High adsorption impact on chemical consumption

Without adsorption mitigation strategy
More than 50% of surfactant is lost
Strategies to mitigate adsorption

Integrated water management strategies

Injection strategy
- Salinity gradient
- Adsorption Inhibitor
- Alkaline
- Chelating Agent

Water treatment
- Salt removal
- Softening
- Salt addition

Case by case choice of the right strategy
Part I

Integrated water management strategies

Injection strategy
- Salinity gradient
- Adsorption Inhibitor
- Alkaline
- Chelating Agent

Water treatment
- Salt removal
- Softening
- Salt addition

Case by case choice of the right strategy
Salinity and hardness have a strong impact on adsorption.

Impact of salinity vs. hardness on adsorption

Adsorption takes place on hard water and at high salinity soft waters.

Softening is the key.

\[ R^+ = \frac{\sum \text{Divalent Cations}}{\sum \text{Total Cations}} = \frac{\sum (\text{Ca}^{2+} + \text{Mg}^{2+})}{\sum (\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+} + \text{Mg}^{2+})} \]

Anionic EOR surfactant
Brine
Crushed Clashach sandstone

Seawater
Hard water
Soft water
A strong salinity gradient can be efficient if the polymer drive salinity is low enough to promote desorption.

Impact of salinity and hardness on adsorption

Implication for water treatment: salt addition or salt removal

Injection sequence
Salinity gradient decreases surfactant adsorption and can increase oil recovery

Surfactant concentration at core outlet

Oil recovery during coreflood test (% ROIP after Sorw)

Adsorption reduction of 60%
Oil recovery improved > 35%
Low adsorption and high additional oil recovery with SG strategy

Chemicals: iOS / AES 8 g/l  HPAM  1,5 g/l
Main slug (0,5 PV), salinity 75 g/l NaCl
Polymer drive (1,6 PV), salinity 40 g/l or 75 g/l

> + 35%
Adsorption inhibitors decrease EOR surfactant adsorption

- Adsorption inhibitors are low cost chemicals which can remobilize adsorbed EOR surfactant.

Higher recovery for same surfactant quantity injected.
Alkaline impact on adsorption depends on rock characteristics

Alkaline impact on adsorption in two different cases

![Bar chart showing adsorption comparison between No Alkaline and Alkaline cases. Case I shows a strong effect on adsorption, while Case II shows a limited effect.]

- **Case I**: Strong effect on adsorption
- **Case II**: Limited effect on adsorption

**Limit of use**
- Hard water in presence of alkaline

**Severe scale risk with hard water**

**Water softening / Salt removal**

The EOR Alliance – SUEZ Environnement
Chelating agent use, an option with limitations

73 g/l of EDTA necessary to chelate 1 g/l of calcium ion

- EDTA is efficient to chelate divalent cations

- Hard water needs large quantity of EDTA
- Limited EDTA availability on the worldwide market
- EDTA HSE concern (corrosive, hazardous poorly degradable)
Part II

Integrated water management strategies

Injection strategy
- Salinity gradient
- Adsorption Inhibitor
- Alkaline
- Chelating Agent

Water treatment
- Salt removal
- Softening
- Salt addition

Case by case choice of the right strategy
Water treatment is tailored to reach the site specific injection specs with a wide variety of feed water chemistries.

**Objectives:**
- Control reservoir souring, scaling & corrosion
- Optimize injection strategy

**Injection specs**
- Salinity: Depends on injection strategy
- Scale forming ions: Depends on injection strategy
- TSS: < 5 ppm
- Oil: < 30 ppm

<table>
<thead>
<tr>
<th>Component</th>
<th>Aquifer</th>
<th>Seawater</th>
<th>Produced Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>+</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Scale forming ions</td>
<td>+ (SO4, Ca, Mg)</td>
<td>++ (Ca, Mg, Ba, Sr)</td>
<td>+++</td>
</tr>
<tr>
<td>TSS</td>
<td>+</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Oil</td>
<td>-</td>
<td>-</td>
<td>+++</td>
</tr>
</tbody>
</table>
### Water treatment technologies to remove hardness

#### Solution

<table>
<thead>
<tr>
<th>Cations</th>
<th>Anions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca, Mg</td>
<td>HCO₃</td>
</tr>
<tr>
<td>Na, K</td>
<td>Cl, SO₄</td>
</tr>
</tbody>
</table>

#### Softening

Remove **total hardness**

- **Na, K**
- **HCO₃**
- **Cl, SO₄**

#### Demineralisation

Remove the **ions**

- **Cl, SO₄**
- **Na, K**

#### Process

- **Precipitation**
- **Ion Exchange**

- **Membrane Filtration**
- **Ion Exchange Thermal**

---

**Designing a Water Treatment Solution requires a Case by Case Approach**

---

The EOR Alliance – SUEZ Environnement
Water treatment technologies
Case Studies

- **Application:** Aquifer Water Softening
- **Process:** Ion Exchange
- **Technology:** SAC Resins

**Limitations:**
- High salinity interferes with the process

**Ease of Handling:**
- Easy handling of Chemicals ($NaCl$)
- Easy handling of By-Products

**Recovery:**

**Robustness:**

**Energy Efficiency:**

**Table:**

<table>
<thead>
<tr>
<th>Aquifer Water</th>
<th>Sea Water</th>
<th>Produced Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Aquifer Water" /></td>
<td><img src="image" alt="Sea Water" /></td>
<td><img src="image" alt="Produced Water" /></td>
</tr>
</tbody>
</table>

**Limitations:**
- High salinity interferes
Water treatment technologies
Case Studies

- Application: Seawater Demineralisation
- Process: Filtration
- Technology: RO/NF membranes

Design philosophy:
- **Offshore**: Optimize the flux to reduce footprint
- **Onshore**: Optimize the recovery

Limitations:
- Max Salinity: 45 g/l
- Max Temp: 40° C
Water treatment technologies
Case Studies

- Application: Produced Water Softening
- Process: Chemical Precipitation
- Technology: Lamella Clarifier

Produced Water → Deoiling step → Chemical Softening → Treated Water to injection → Sludge to dewatering and disposal

Energy efficiency
Easy handling of By-Products
Recovery
Robustness
Easy handling of Chemicals

Aquifer Water | Sea Water (Offshore) | Produced Water
---|---|---
Green | Red | Green

Limitations:
Min. achievable hardness in treated effluent: 30 ppm as CaCO₃

The EOR Alliance – SUEZ Environnement
Part III

Integrated water management strategies

Injection strategy
- Salinity gradient
- Adsorption Inhibitor
- Alkaline
- Chelating Agent

Water treatment
- Salt removal
- Softening
- Salt addition

Case by case choice of the right strategy
## Comparison of Chemical EOR cost

### Water studied

<table>
<thead>
<tr>
<th></th>
<th>Aquifer</th>
<th>Sea water</th>
<th>Produced water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TDS [ppm]</strong></td>
<td>2 000</td>
<td>35 000</td>
<td>50 000</td>
</tr>
<tr>
<td><strong>Hardness [ppm as CaCO₃]</strong></td>
<td>810</td>
<td>5 790</td>
<td>10 210</td>
</tr>
<tr>
<td><strong>R⁺</strong></td>
<td>0,44</td>
<td>0,17</td>
<td>0,27</td>
</tr>
</tbody>
</table>

### c-EOR process

- SP
- SP + SG
- SP + AI
- ASP + SG

- **Polymer drive**: 0.8 PV
- **SP slug**: 0.3 PV
- **Water**: 5 PV
Comparison of Chemical EOR cost

- **System**
  - Sandstone reservoir rock
  - 100,000 bbl water injected per day
  - Oil viscosity around 2 cps
  - Mineralogy and oil suitable for Alkaline use

- **Hypothesis**
  - Surfactants injected to cover adsorption of swept area
  - Same level of performance achieved with various scenarios (40% incremental oil)
  - From lab to field: 20% incremental oil (swept area)

- **Costing**
  - Chemical supply (Surfactant, Polymer, Adsorption inhibitor, salt)
  - Water treatment facility (CAPEX & OPEX)
Comparison of Chemical EOR cost

- Surfactant Polymer
- Surfactant Polymer Salinity Gradient
- Surfactant Polymer Adsorption Inhibitors
- ASP Salinity Gradient
- Adsorption

Suitable injection strategy can reduce chemical EOR cost by a factor 2

- Cost per incremental bbl ($)
- Surfactant adsorption mg/g

Aquifer | Sea water | Produced water

Water treatment:
- ✓
- ✓
- ✓
- ✓
- ✓
Conclusion

Choice of water management strategy

Solutions exist to make chemical EOR projects economic

Case by case study required to select appropriate strategy

Need to be considered early in project

Requires involvement of complementary expertise
Water Management Strategies to Improve Chemical EOR Economics

Chemical EOR Workshop – Key success factors
2015 Edition