VISCOELASTIC SURFACTANTS FOR OIL RECOVERY
PRIMARY RECOVERY

Produces 2-15% Original Oil in Place

SECONDARY RECOVERY

Another 15-20% OOIP may be produced by water flooding

ENHANCED OIL RECOVERY

Another 4-35% OOIP may be produced by EOR

EOR Process

• Thermal
• Gas miscible
• Chemical

• Microbial
• Gravity Mining

Approx. 460 billion bbls OIP before any production

Approx. 65% 300 billion bbls OIP after secondary recovery
CHEMICAL EOR

EOR may include surfactant, polymer and alkaline flooding. After a reservoir is conditioned by a water preflush, specific chemicals are injected to reduce the IFT (help to release oil) and improve mobility control (reduce channeling).
TWO PRIMARY MECHANISMS IN CHEMICAL EOR

- Reduce interfacial forces
- Improve sweep efficiency & mobility ratio
TWO PRIMARY MECHANISMS IN CHEMICAL EOR

- Reduce interfacial forces
  - surfactants
- Improve sweep efficiency & mobility ratio
ROLE OF IFT
## SURFACE TENSION & INTERFACIAL TENSION

<table>
<thead>
<tr>
<th>Description</th>
<th>ST or IFT, mN/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>72</td>
</tr>
<tr>
<td>Oil</td>
<td>6-40</td>
</tr>
<tr>
<td>Oil/Water</td>
<td>3-30</td>
</tr>
<tr>
<td>O/W with 0.05-0.2% EOR surfactant</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
RELATIONSHIP BETWEEN CAPILLARY NUMBER AND OIL RECOVERY

\[ Nc = \frac{\nu \mu}{\sigma \cos \theta} \]

- \( Nc \) = Capillary Number
- \( \nu \) = Darcy Velocity
- \( \mu \) = Viscosity
- \( \sigma \) = Interfacial Tension
- \( \theta \) = Wetting angle

TWO PRIMARY MECHANISMS IN CHEMICAL EOR

- Reduce interfacial forces
  - Surfactants
- Improve sweep efficiency & mobility ratio
TWO PRIMARY MECHANISMS IN CHEMICAL EOR

- Reduce interfacial forces
  - Surfactants
- Improve sweep efficiency & mobility ratio
  - Polymers
OIL CONTAINING CORE

INJECTION FLUID CAN CHANNEL THROUGH LARGE FRACTURES AND BY-PASS OIL
## POLYMERS USED IN EOR

<table>
<thead>
<tr>
<th>POLYMER</th>
<th>HIGH TEMP</th>
<th>HIGH TDS</th>
<th>HIGH SHEAR</th>
<th>COST</th>
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<tbody>
<tr>
<td>Polyacrylamide</td>
<td>75°C</td>
<td>poor</td>
<td>poor</td>
<td>low</td>
</tr>
<tr>
<td>AMPS copolymer</td>
<td>90°C</td>
<td>fair</td>
<td>poor</td>
<td>medium</td>
</tr>
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<td>Xanthan gum</td>
<td>50°C</td>
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TWO PRIMARY MECHANISMS IN CHEMICAL EOR

- Reduce interfacial forces
  - surfactants
- Improve sweep efficiency & mobility ratio
  - Polymers
  - Viscoelastic surfactants
VISCOELASTIC SURFACTANT

- Forms viscoelastic solution at 0.1-1.0 wt%
- Reduces IFT to below 0.01 mN/m
- Tolerant to high TDS and hardness
- Shear thinning and reversible
- Viscosity is reduced when contacted with oil
- Diverts injection fluid to oil bearing sites
- Thermal stability above 150C
## POLYMERS USED IN EOR

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<td>fair</td>
<td>fair</td>
<td>high</td>
</tr>
<tr>
<td>Viscoelastic surf.</td>
<td>150°C</td>
<td>excellent</td>
<td>excellent</td>
<td>low</td>
</tr>
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</table>
EFFECT OF SHEAR ON VISCOELASTIC SURFACTANT

![Graph showing the effect of shear on viscosity](image-url)
EFFECT OF TEMPERATURE
0.5% @150°C

DAYS
VISC, CPS

1 10 100 1000
MECHANISM OF VISCOELASTIC SURFACTANT FLOODS
WATER FLOOD

Water channels through the formation
WATER FLOOD

Injector

Producer
WATER FLOOD

Injector

Producer

Injector

Producer
WATER FLOOD

Injector

Producer
WATER FLOOD

Injector

Producer
WATER FLOOD

Injector

Producer
SURFACTANT FLOOD

Surfactant follows the water channels through the formation
SURFACTANT FLOOD

Injector

Producer
SURFACTANT FLOOD

Injector

Producer
SURFACTANT FLOOD

Injector

Producer
SURFACTANT FLOOD

Injector

Producer
SURFACTANT FLOOD

Injector

Producer
SURFACTANT FLOOD
VISCOELASTIC SURFACTANT FLOOD

Injection fluid containing viscoelastic surfactant seeks out oil-bearing channels, blocks water channels.
VISCOELASTIC SURFACTANT

Injector

Producer
VISCOELASTIC SURFACTANT
VISCOELASTIC SURFACTANT
VISCOELASTIC SURFACTANT
VISCOELASTIC SURFACTANT

Injector

Producer
VISCOELASTIC SURFACTANT

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Injector

Producer
VISCOELASTIC SURFACTANT
VISCOELASTIC SURFACTANT
35000 TDS, 1700 Ca/Mg
0.1% surfactant
0.6% smart surfactant
35000 TDS, 1700 Ca/Mg
0.1% surfactant
0.6% smart surfactant

% Recovery OOIP

PV Injected

15 PV surfactant
15 PV water
15 PV water

%OOIP
CUM, %
35000 TDS, 1700 Ca/Mg
0.1% surfactant
0.6% viscoelastic surfactant
35000 TDS, 1700 Ca/Mg
0.1% surfactant
0.6% viscoelastic surfactant

% Recovery OOIP

PV Injected

15 PV surfactant
15 PV water
2 PV viscoelastic surfactant
13 PV water

%OOIP
CUM, %
VISCOELASTIC SURFACTANT STRUCTURE

Work-like viscoelastic surfactant micelles for viscosity

Cosurfactant for low IFT
APPLICATION OF VISCOELASTIC SURFACTANTS

- **Viscoelastic Surfactants Alone** –
  - Tight formations, high temperatures, high salinities

- **Viscoelastic Surfactants With Polymers** -
  - High viscosity oils, polymer gives residual viscosity when contacting oil
RESIDUAL OIL RECOVERY TEST

Begin Surfactant Addition
0.3 Pore Volume, 0.5%
APPLICATION OF VISCOELASTIC SURFACTANTS

- **Viscoelastic Surfactants Alone** –
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- **Viscoelastic Surfactants With Polymers** –
  - High viscosity oils, polymer gives residual viscosity when contacting oil

US PATENT 7,373,977
<table>
<thead>
<tr>
<th>Description</th>
<th>IFT, mN/m</th>
<th>Visc, cps</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 0.05% anionic surfactant</td>
<td>Ppt</td>
<td>Ppt</td>
</tr>
<tr>
<td>B 0.45% viscoelastic</td>
<td>0.092</td>
<td>62</td>
</tr>
<tr>
<td>C A+B before oil contact</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>D A+B after oil contact</td>
<td>0.0042</td>
<td>2.7</td>
</tr>
<tr>
<td>E 0.010% polyacrylamide</td>
<td>2.8</td>
<td>10</td>
</tr>
<tr>
<td>F C+E</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>G D+E</td>
<td>0.0051</td>
<td>11</td>
</tr>
</tbody>
</table>
CONCLUSIONS

- Viscoelastic surfactants have been developed that provide both low IFT and high viscosity in injection fluids.
- Unlike polymers, viscoelastic surfactants are not permanently degraded by high shear.
- Also, unlike polymers their viscosity building characteristics are not reduced by high electrolyte concentrations.
- Viscoelastic systems can be designed to tolerate both high temperature and high salinity conditions.
THANK YOU!

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