SURFACTANT INJECTION PROJECTS - FIELD CASES

Christie Lee / Paul Berger
Oil Chem Technologies, Inc.
- Research and develop surfactants exclusively for EOR since 1995
- Worked closely with the operators to custom design and optimize surfactants/processes based on the need of each project
- Field proven products and processes – more than 50 million pounds of surfactants successfully injected all over the world.
- Continuously improve and develop products/processes based on field results and aimed for the future
- No. 6 fastest growing company in energy in USA
ARE THERE CHEMICAL EOR PROJECTS?

Injection fluid

Injection well

Injection Pump

Producing well

Oil

SS B2080, SS B5050, ORS-46L, ORS-97HF, ORS-41HF, SS-1688,

ORS-57HF, ORS-41HF

SS 6046, SS GI1416

ORS-41HF, SS B1688, SS-890

ORS-41(4) *, SS B1688, FI-100

SS B8020

SS 6-72

ORS-41, SS-6566, ORS-57

INJECTED, ON-GOING & APPROVED PROJECTS
PRESENTATION OUTLINE

- Chemical EOR – Past
- Chemical EOR – Present
  - Oil Chem field experience to share
- Chemical EOR – Problems/solution
- Conclusions
PRESENTATION OUTLINE

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## EOR IN EARLY 1980’S

<table>
<thead>
<tr>
<th>Field</th>
<th>Loudon</th>
<th>Big Muddy</th>
<th>Robinson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfactant Conc.</td>
<td>2 surfactants 2.3%</td>
<td>3%</td>
<td>10%</td>
</tr>
<tr>
<td>Pore Volume</td>
<td>0.3</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Co-solvent</td>
<td>- - -</td>
<td>5% iso-butanol</td>
<td>0.6% hexanol</td>
</tr>
<tr>
<td>Salt</td>
<td>96% connate salinity</td>
<td>0.6%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Polymer</td>
<td>0.1% xanthan</td>
<td>0.22% polyacrylamide</td>
<td>None</td>
</tr>
<tr>
<td>Recovery</td>
<td>68% RIOP</td>
<td>15% RIOP</td>
<td>19-21% ROIP</td>
</tr>
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EOR BY CHEMICAL FLOOD

Never really took off in the past - Reasons?
- Sensitivity to oil price
- Large up-front investment
- Unpredictable return on investment
- High surfactant concentration
- Salinity optimization required
- Optimum salinity shift in the formation
- Potential emulsion block
- Economic feasibility
However,

- Extensive lab evaluations support the feasibility of chemical flooding
- Field data proves chemical flooding is an effective way to recover residual oil
- New chemicals and processes open the door for new opportunities
## COST OF CHEMICALS

<table>
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<tr>
<th></th>
<th>1980 Micellar</th>
<th>2008 (Oil Chem’s surfactant /process)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer</td>
<td>$3-4/lb</td>
<td>$1 – $1.8/lb</td>
</tr>
<tr>
<td>Surfactant¹</td>
<td>$0.40-$0.60/lb</td>
<td>$0.80-$1.5/lb</td>
</tr>
<tr>
<td>Alkali²</td>
<td>$0.12/lb</td>
<td>$0.30 – $0.60/lb</td>
</tr>
<tr>
<td>Crude Oil</td>
<td>~ $12/bbl</td>
<td>$60-$140/bbl</td>
</tr>
<tr>
<td>Incr. Cost/bbl</td>
<td>$8 - &gt; $15</td>
<td>$2 - $10</td>
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¹ Surfactant concentration has been reduced by 10 times as compared to 1980’s
² Alkali has been reduced or in some cases is not needed at all
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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

Over 100 surfactants were evaluated in the lab during 1992-94 including:

- ORS-41
- Petroleum Sulfonates
- Carboxylates
- Lignin Sulfonate/Petroleum Sulfonates
- Microbiological
1995 - INITIAL FIELD EVALUATION

- Daqing No.4 Field - Oil Chem Technologies’ ORS-41
- Daqing No.1 Field – another US company’s Petroleum Sulfonate
ORS-41 was chosen as the only surfactant for enlarged field flood. More than 7000 MT of the ORS-41 was injected in several field blocks and this confirmed the viability of the ASP process. Cost was $3.74/bbl of incremental oil.

SPE 36748, 57288, 71061, 71491, 71492
ASP PROJECT USING ORS-41™ IN DAQING, CHINA

Oil Recovery Tons/Day

Well Number

BEFORE ASP
AFTER ASP

SPE 36748 (1996)
**HUSKY TABER ASP PROJECT**

ORS-97HF

- **Begin ASP 6/2006**
- **4/2008 10.2% oil cut**
- **4/2008 2087 bbls/day**
- **300 bbls/day**
- **1.7% oil cut**

**Graph Details:**
- Y-axis: % Oil Cut and Oil Production
- **Oil Cut** (red line)
- **Oil Production** (yellow line)

Masterenergy.com
CANADA SP PROJECT

- Heavy oil field
- Under polymer flood
- Added 0.1% surfactant with polymer in November, 2006
- ~ 3 months later, the water cut reduced from 97% to 58%
USA EOR PROJECTS
The Lawrence Field - estimated one billion barrels of original oil-in-place

The Cypress (Mississippian) and the Bridgeport (Pennsylvanian) sandstones are the major producing horizons in the field.

Produced more than 400 million barrels (40%) of oil since its discovery in 1906.

WWW.REXENERGYGROUP.COM
During 2007, core floods resulted in an oil recovery rate of 21% OOIP for Cypress, and 24% OOIP for Bridgeport.
In 2006 and 2007, 18 wells drilled in two pilot areas.
2008- pilot ASP injection started.
Bridgeport Sandstone is demonstrating an initial response to the ASP chemical injection as indicated by an increase in the oil cut ratio in the pilot wells.
REX ENERGY ASP PROJECTS

- Cypress Sandstone ASP pilot is continuing to demonstrate a response to the ASP chemical injection.
- Plans to implement a broad ASP flood program within the 13,500 net acres of the field commencing in 2009 based on successful pilot runs in either field.

WWW.REXENERGYGROUP.COM
TANNER FIELD, WYOMING
ASP PROJECT

- Crude oil : 21° API
- Bottom Hole Temperature: 175°F
- Depth: 8915 ft
- Thickness: 25 ft
- Porosity: 20%
- Permeability: 200 mD

SPE 100004
Tanner, Wyoming
Alkaline-Surfactant-Polymer Flood

SPE 100004
SHO-VEL-TUM FIELD
ASP PROJECT

- On production > 40 yrs, extensive water flood, produced 4 bbl/day
- ASP started on 2/98, using Na$_2$CO$_3$ and ORS-62
- Total incremental oil > 10,444 bbl in 1.3 years
  (A 500% increase in production)

SPE 84904
OIL SATURATION AFTER ASP INJECTION

So, %PV vs. (SURFACTANT CONC, %) (ASP SLUG SIZE)

SPE 84904
BIG SINKING FIELD, KY
Surfactant Assisted Water Flood

- 100 Million barrels oil-in-place
- Depth 1150 feet
- BHT 30°C
- Thickness 25 feet
- Permeability 45 mD
- High water cuts and very low injectivity

SPE 89384
BIG SINKING, KENTUCKY

Surfactant Assisted Water Flood

Chemical injected:
0.8% NaOH + 0.1% ORS-162HF

Problems overcome:
- IFT lowered from 23.6 to 0.001 mN/m
- Poor water injectivity
- High water cuts
- 220% increase in injectivity
- Large field trial scheduled to begin in 12/2007

SPE 89384
SOUTH AMERICA PROJECTS
ARGENTINA SP PROJECT

- SP injection using SS-1688, injection started in September, 2007
- Initial surfactant Injection – 1000 ppm, tapered down to 250 ppm after 6 months
- No alkali, no salinity optimization, no co-solvent is used
- Oil production Increased ~50% and ~80% after 4 months for 2 blocks
SOUTHEAST ASIA
OFFSHORE ALKALINE SURFACTANT (AS) PROJECT

- Sea water is softened on the platform
- Single well test successfully performed using SS 6-72LV injected with NaOH
- Pilot project will proceed

SPE 100943, 109033
PROJECTS SUMMARY

- Only selected, published data has been presented to maintain the confidentiality of the producers.
- More than 50 million pounds of Oil Chem’s surfactants have been successfully injected.
- Equivalent to ~ 143 million bbl of the injection fluid at 0.1% surfactant.
- Processes included ASP, SP, S and heavy oil recovery.
PRESENTATION OUTLINE

- Chemical EOR – Past
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EXPERIENCE GATHERED FROM THE FIELD PROJECTS

- Success
- Problems encountered
- Solutions
- Improvement
S. M. Faroug Ali, Univ. Of Calgary:

WHY EOR HAS NOT LIVED UP TO EXPECTATION?

- Some of the oil recovery methods suffer from limitations not easily understood from unscaled lab experiments – field failures were the only way to understand them.
- In many cases, reservoir description/heterogeneity is the problem.
- Economics are the key to large scale application of even tested processes.
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PROCESS COMPARISONS

Typical ASP vs Oil Chem ASP

Typical ASP Flood

A
PROCESS COMPARISONS

Typical ASP vs Oil Chem ASP

Typical ASP Flood

A

S1

0.2 – 2%
PROCESS COMPARISONS
Typical ASP vs Oil Chem ASP

Typical ASP Flood

A
S1
0.2 – 2%
S2
0.2 – 2%
PROCESS COMPARISONS
Typical ASP vs Oil Chem ASP

Typical ASP Flood

A  S1  S2  Co-surf.
0.2 – 2% 0.2 – 2% 0.2 – 4%
PROCESS COMPARISONS
Typical ASP vs Oil Chem ASP

Typical ASP Flood

- A: 0.2 – 2%
- S1: 0.2 – 2%
- S2: 0.2 – 2%
- Co-surf.: 0.2 – 4%
- NaCl: 0.5–5%
PROCESS COMPARISONS

Typical ASP vs Oil Chem ASP

Typical ASP Flood

A

S1
0.2 – 2%

S2
0.2 – 2%

Co-surf.
0.2 – 4%

NaCl
0.5–5%

P

~ $10 - $30/bbl Incremental Oil
PROCESS COMPARISONS
Typical ASP vs Oil Chem ASP

Typical ASP Flood

- A
- S1: 0.2 – 2%
- S2: 0.2 – 2%
- Co-surf.: 0.2 – 4%
- NaCl: 0.5-5%
- P

~ $8-20/bbl Incremental Oil

Oil Chem Typical ASP Flood

- A
PROCESS COMPARISONS

Typical ASP vs Oil Chem ASP

Typical ASP Flood

A
0.2 - 2%

S1
0.2 - 2%

S2
0.2 - 2%

Co-surf.
0.2 - 4%

NaCl
0.5-5%

P

~ $8-20/bbl
Incremental Oil

Oil Chem Typical ASP Flood

A
0.1 - 0.3%

S1
0.1 - 0.3%
**PROCESS COMPARISONS**

**Typical ASP vs Oil Chem ASP**

**Typical ASP Flood**
- A
- S1 0.2 – 2%
- S2 0.2 – 2%
- Co-surf. 0.2 – 4%
- NaCl 0.5 - 5%
- P
- Incremental Oil: ~ $8 - 20/bbl

**Oil Chem Typical ASP Flood**
- A
- S1 0.2 – 2%
- P
- Incremental Oil: ~ $4 - $10/bbl
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EFFECT OF SALT ON VISCOSITY

Alcoflood 1175L
NaCl Concentration, wt%:
- 0.0
- 0.01
- 0.05
- 0.2
- 1.4
- 8.2

$T = 20^\circ C$
Polymer Concentration = 1000 ppm

Shear Rate, s$^{-1}$

Viscosity, mPa.s
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SP FLOODS –
ADVANTAGES / PROBLEMS

- Advantages
  - No alkali
  - No water softening
  - No salinity optimization
  - Better polymer performance

- Problems
  - High adsorption
LOW ADSORPTION SURFACTANTS (Patent Pending)

<table>
<thead>
<tr>
<th></th>
<th>Carbonates Avg., mg/g</th>
<th>Sandstone Avg., mg/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anionic Surfactants</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Amphoteric Surfactants</td>
<td>1.0</td>
<td>&gt; 3</td>
</tr>
<tr>
<td>New Low Adsorption Surfactants</td>
<td>0.1 – 0.8</td>
<td>0.1 – 0.8</td>
</tr>
</tbody>
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No Salinity Optimization Is Required!
HEAVY OIL RECOVERY
HEAVY OIL RECOVERY

- CO₂
- Steam
- SAGD
HEAVY OIL RECOVERY - NEW DEVELOPMENT

- Reduce heavy oil viscosity by creating water external pseudo-emulsion
- Reduce the polymer viscosity required by reducing the crude oil viscosity
- Reduce the energy provided by steam to mobilize the oil
HEAVY OIL PSEUDO-EMULSION

Control

0.1% SF-100 Surfactant

Oil Viscosity = 6,700 cps

Oil Viscosity < 200 cps
HEAVY OIL PROJECT
(70°C, 12 API)

Before

After

MT/day

OIL

WATER
PRESENTATION OUTLINE

- Chemical EOR – Past
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CONCLUSIONS

- Worldwide “un-recoverable” oil ~ two trillion bbl oil
- Mostly in depleted reservoirs or those nearing depletion
- Oil reserves and reservoir characteristics have already been confirmed
- Conventional Oil Recover Factor <33%
- Today’s demand for oil makes chemical EOR an effective and economic means of increasing the oil supply
Recent successes in the field have confirmed that chemical EOR is a viable technique. New chemicals and processes have been developed to increase the effectiveness and the economics of EOR, including some extreme reservoir conditions.
CONCLUSIONS

How To Choose Chemicals On Your EOR Projects? Be Aware of:

- State of the art products/process available
- Field proven chemicals
- Field proven process
- Work with experts in each area based on their expertise and field experiences, field success
- Team work, direct involvement
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