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Development of Mature Oil Fields: Enhanced Oil Recovery Option

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Professor and NSERC-IRC in Unconventional Oil Recovery
University of Alberta
OUTLINE

• What is a mature field?
• How much oil is left and where it is
• Recovery of remaining oil: Tertiary recovery
  • Laboratory scale
  • Field scale
• Key points and suggestions
What is a Mature Field?

- **Rate**: Producing but declining
- **Recovery Factor**: 50% - 60 years (99% water cut)
- **Recovery Factor**: 10% - 60 years (0% water cut)
Giant Field Discoveries

OIL FIELDS IN THE WORLD: 30,000
TOTAL RESERVES: 150 MMMm³

33 Fields: 50%

OGJ, Feb. 3, 2014
Additional reserves are from new discoveries or existing fields?

50-70% left behind!!!
Stages In Mature Field Development

BROAD SUBJECT

Well

- WELL ENHANCEMENT
  - Optimization of lift
  - Well stimulation
  - Re-visiting wells

- DRILLING
  - Verticals / Horizontals
  - Multilaterals / Side-tracking
  - Infills

Reservoir

- SECONDARY RECOVERY
  - Pressure maintenance
  - Waterflooding
  - Gas (immiscible) injection

- TERTIARY RECOVERY
  - Gas (CO₂, hydrocarbon-rich)
  - Chemical (surfactant, micellar)
  - Thermal (air)
Development of Mature Fields

**Advantages**
- Data and experience gained
- History
- Modern technologies

**Disadvantages**
- Cost
- Efficiency
- Time to start the project

- Incremental OIL (How much)
- Recovery TIME (How fast)
- **COST** (How expensive)
  - Company Size
  - Long/Short Term
What is Mature Field?

TERTIARY vs. SECONDARY

Recovery is lower - Investment is higher

Company’s cut-off limit for cost: $10, $30, $50/bbl?
Your target is residual oil reduction rather than rate?
Elements of Mature Field Development
(Tertiary Recovery)

How much oil is left and where it is

Tertiary recovery
  Laboratory
  Field
Determination of Remaining Oil Saturation

- Core Analysis
- Logs
- Reservoir Engineering Studies
- Production Data
- Chemical Tracers
- Well Testing (with core analysis)
Remaining Oil Saturations – Different Methods
(33 sandstone fields)

Determination of Residual Oil Saturation, Bond, Hocott, Poettmann (Eds.), Interstate Oil Compact Comm., 1978
## Remaining Oil Saturations – Different Methods

<table>
<thead>
<tr>
<th>Field</th>
<th>RESIDUAL OIL</th>
<th>SOLUTION</th>
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<tbody>
<tr>
<td></td>
<td>Material Balance (% PV)</td>
<td>Tracer Test (%PV)</td>
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<tr>
<td>1</td>
<td>16</td>
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</table>

-Determination of Residual Oil Saturation, Bond, Hocott, Poettmann (Eds.), Interstate Oil Compact Comm., 1978
Cased Hole Formation Resistivity Logs

- Nuclear logs (Neutron, C/O): Not reliable
- New tool for resistivity through metal casing

Cement squeeze
Re-perforate

Oil: From 34 to 253 bbl/d
Water: Completely stopped

(Petrophysics, 2004 no.4)
Remaining Oil Saturation: Yates Field

- Discovered in 1927
- 1.3 billion barrel produced
- Strongly heterogeneous mixed wet carbonate
- 1100 producers - 57 injectors (1992)

PROBLEMS

\[ S_w = \left( \frac{aR_w}{\varphi^m} \right)^{\frac{1}{n}} \]

- \( n \) and \( m \) between 1 and 5 (in space - time)
- Borehole filled with gas, no electromagnetic propagation

SOLUTION: NMR

- Alternative to resistivity saturation.
- Insensitive to gas
- Oil/water by diffusion coefficient
Comparison: Remaining Oil Saturation (ROS)

ROS (Core, log, tracer) \(<\) ROS (Material balance)

ROS (Pulsed Neutron Capture) \(\equiv\) ROS (Resistivity)

ROS (Single well tracer) \(<\) ROS (Logs)
Tertiary Recovery – Field Applications

- Immiscible gas injection
  - Double displacement
  - Inert gas
- Miscible gas injection
  - HC gases
  - CO₂
- Chemical (surfactant) injection
Tertiary Gas Injection Applications

Unknown % of Incremental Tertiary Recovery

Field (Discovery Year)
Tertiary Chemical Injection Applications

<table>
<thead>
<tr>
<th>Field (Discovery Year)</th>
<th>Micellar surfactant polymer</th>
<th>Alkaline surfactant polymer</th>
<th>Alkaline polymeer</th>
<th>Surfactant injection</th>
<th>Polymer</th>
<th>Polymer (Pilot)</th>
<th>Polymer flood</th>
<th>Micellar Polymer</th>
<th>Micro emulsion</th>
<th>Low IFT polymer</th>
<th>Caustic (35000-47000 stb)</th>
<th>Alkaline surfactant polymer (65000 bbls)</th>
<th>Unknown % of Incremental Tertiary Recovery</th>
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<td>Bradford (1871)</td>
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<td>David Pool (1970)</td>
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<td>Marvel (1944)</td>
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<td>Whittier (1966)</td>
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<td>Big Muddy (1916)</td>
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<td>Pownall Ranch (1974)</td>
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</table>
Surfactant Flood: Incremental Recovery

Loudon Field: 13 years primary, 38 years waterflooding.

Remaining oil: 50 % OOIP

CORE FLOOD RESULTS

- Residual Oil After Waterflooding
- Final Oil Saturation After Surfactant Flood

5-30%

SPE 20218
Micellar Flood (Composition)

<table>
<thead>
<tr>
<th>Type</th>
<th>Oil (%)</th>
<th>Brine (%)</th>
<th>Surfactant (%)</th>
<th>Co-Surfactant (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>64</td>
<td>20</td>
<td>12</td>
<td>4 (Isopropyl Alcohol)</td>
</tr>
<tr>
<td>T1</td>
<td>85</td>
<td>5</td>
<td>8.5</td>
<td>1.5 (Isopropyl Alcohol)</td>
</tr>
<tr>
<td>P2</td>
<td>6</td>
<td>84</td>
<td>7.5</td>
<td>3 (Cyclohexanol)</td>
</tr>
<tr>
<td>T2</td>
<td>2</td>
<td>93</td>
<td>4</td>
<td>1.5 (Cyclohexanol)</td>
</tr>
</tbody>
</table>
Sequence of Methods

Flue gas injection as water-alternating-gas (WAG)

14 °API Oil

- Initial Oil
- Residual Oil (Gas Injection)
- Residual Oil (Blow Down)
- Residual Oil (Waterflooding)
- Residual Oil (Extended Waterflooding)

Oil Saturation, % OOIP

Tertiary WAG
Secondary Slug

Tertiary Recovery by Hydrocarbon Solvent

Miscibility after waterflood

- Solvent invade only water filled pores.
- Oil may not be displaced from the smaller pores.
- Water film between solvent and oil/grain

Grain  Water  Oil

Heptane

200 microns
Tertiary Recovery by Solvent

Kerosene (2 cp)

Solvent → Water

Water → Solvent → Water

RF=69%

RF=47%
# Tertiary Recovery by Solvent

**Kerosene (2 cp) - Mixed Wet**

<table>
<thead>
<tr>
<th>Solvent → Water</th>
<th>Water → Solvent → Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mixed wet</strong></td>
<td>RF = 85%</td>
</tr>
<tr>
<td><strong>Water wet</strong></td>
<td>RF&lt;sub&gt;water&lt;/sub&gt; = 73%</td>
</tr>
<tr>
<td></td>
<td>RF&lt;sub&gt;final&lt;/sub&gt; = 64%</td>
</tr>
<tr>
<td></td>
<td>RF&lt;sub&gt;water&lt;/sub&gt; = 66%</td>
</tr>
<tr>
<td></td>
<td>RF&lt;sub&gt;final&lt;/sub&gt; = 47%</td>
</tr>
</tbody>
</table>
YIBAL FIELD

- Big field: 450 wells
- Long term targets
- High investment
- Chalky carbonate
- Light oil (1cP)
- Natural water influx
Experiments in ascending order

- Water Injection
- Surfactant Injection After Waterflooding
- Continued With Another Surfactant
- Surfactant Injection

Yibal Field (Chalk) Dilute Surfactant Performance

Oil Recovery, % OOIP

WATER INJECTION ONLY = 75%
SURFACTANT ONLY = 70%
SAHMAH FIELD

- Small field: 20 wells
- Small company
- Short term targets
- Low investment

- Sandstone
- Oil: 45 oAPI, 1 cP
- Natural water influx
- Deep: 3,250m

- Two sandstone layers:
  - Low permeability (1 mD), RF=10%
  - High permeability (150 mD), RF=70%

2002
Nitrogen injection into tight zone

Sandstone, $\phi = 20.38\%$, $k=3.68$ mD

Time, min.

Oil Recovery, decimal (OOIP)

Injection Pressure, psi

Recovery

Pressure
Nitrogen injection into waterflooded zone

Sandstone, $\phi = 15\%$, $k=127$ mD

- Water Injection ($q=1$ cc/min)
- Nitrogen injection started

Recovery by Water
Recovery by Nitrogen
Pressure

Injection Pressure, psi

Oil Recovery, decimal (OOIP)
Field scale simulation

One converted injector

Oil Production, m³/day

Time (days)

Base case

8250 psi

6750 psi

5250 psi

3750 psi

One converted injector
Concluding Remarks

• Locate the remaining oil
• Proper tertiary recovery method
  • Small companies → faster recovery (short term)
  • Big companies → higher ultimate recovery (long term)
• Laboratory experiments
  • When to start tertiary recovery
  • Role of water (or gas) saturation history
  • Interaction with injectant to reduce residual oil saturation
  • Injection design (sequence, WAG ratios, slug sizes)
Further Suggestions

• Be proactive: Forecast the impacts a few decades ahead
• Reservoir characterization for optimal design
• Human factor: Experience and expertise
Bottom Line

No luxury of leaving ~50% of oil trapped in mature and marginal fields.

The careful selection and design of technically and economically viable technique.
Your Feedback is Important

Enter your section in the DL Evaluation Contest by completing the evaluation form for this presentation

http://www.spe.org/dl/