Waterflooding

A Tried and True Technique for Secondary Oil Recovery

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General Topics

• What is a “waterflood”?
• How does it work?
• What types of properties make better candidates?
• Unitization
  – Why is it sometimes needed?
  – How does the process work?
  – Example equity formula
What is a Waterflood?

• It is the injection of water into a wellbore to push, or “drive” oil to another well where it can be produced

• Recognized enhanced oil recovery technique since early 1900’s

• Some oil reservoirs have natural water influx, which increases oil production
  – Called “water drive” reservoirs
  – They are natural “waterfloods”
How Does a Waterflood Work?

• Oil reservoirs and “Original Oil in Place”
• Oil recovery under “primary” production
• Target oil for waterflood recovery
Bulk Volume Calculations

Reservoir Area

Reservoir Bulk Volume (BV) :
BV = Area x Thickness

Calculating Original Oil in Place (OOIP)

- **Bulk Volume**
  - Area
  - Thickness

- **Porosity**
  - Pore space within the rock
  - Generally 5% to 30% of the bulk volume
Calculating Original Oil in Place (OOIP)

- **Bulk Volume**
  - Area
  - Thickness
- **Porosity**
- **Fluid saturations**
  - Water (usually 10% to 50% of pore space)
  - Oil
Calculating Original Oil in Place (OOIP)

- Bulk Volume
  - Area
  - Thickness
- Porosity
- Fluid saturations
  - Water
  - Oil
- Shrinkage (oil formation volume factor)
Formation Volume Factor (Bo)

• Oil “shrinks” as it is produced from the reservoir to the surface due to...
  – gas evolving from the oil
  – Lower temperature at the surface

• The sales unit for oil is a “stock tank barrel”, or STB, which is equal to 42 US gallons

• Units of Bo are RB/STB (reservoir barrels per stock tank barrel)

• Bo in typical waterflood projects ranges from about 1.1 to 1.5 RB/STB
Calculating Original Oil in Place (OOIP)

\[ \text{OOIP} = 7,758 \times A \times h \times \phi \times (1 - S_w)/B_o \]

Where:

- \( \text{OOIP} \) = original oil in place, STB
- \( 7,758 \) = factor converting acre-feet to barrels
- \( A \) = reservoir area, acres
- \( h \) = average reservoir thickness, feet
- \( \phi \) = average reservoir porosity, fraction bulk volume
- \( S_w \) = average water saturation, fraction pore volume
- \( B_o \) = oil formation volume factor, RB/STB
Example Calculation

Problem - Calculate OOIP oil for a new oil well with the following conditions:
Reservoir area = 40.0 acres
average reservoir thickness = 25 feet
average reservoir porosity = 22%
average water saturation = 30%
oil formation volume factor = 1.32 RB/STB
Example Calculation

\[ \text{OOIP} = \frac{7,758 \times A \times h \times \phi \times (1 - S_w)}{B_o} \]

\[ \text{OOIP} = \frac{7,758 \times 40 \times 25 \times 0.22 \times (1 - 0.30)}{1.32} \]

\[ \text{OOIP} = 905,100 \text{ STB} \]
So once we’ve calculated OOIP......
So once we’ve calculated OOIP……

How much of that oil is recoverable?

The Amount of Recoverable Oil Depends on the Natural (Primary) Reservoir Drive Mechanism

• Solution Gas Drive
  – Recovers 5% to 15% OOIP
  – Leaving behind 85% to 95% of the OOIP

• Solution Gas Drive + Gas Cap Expansion
  – Recovers 15% to 25% OOIP
  – Leaving behind 75% to 85% of the OOIP

• Natural Water Drive
  – Recovers 25% to 50% OOIP
  – Leaving behind 50% to 75% of the OOIP
Why would you need to waterflood?

• MANY (majority?) oil reservoirs are solution gas drive
• Waterflooding can recover much of the oil left behind under “Primary” production, especially a solution gas drive system
• Since waterflooding usually follows “primary” production, it is often called a “secondary” recovery technique
How does a waterflood work?

• Certain oil wells are converted to water injection wells
• Other oil wells remain as producers
• The injected water displaces, or “pushes” oil to the producing wells
Waterflood Example

PRIMARY PRODUCTION

Waterflood Example

Waterflood Example

WATERFLOOD PATTERN
5-SPOT

producing well (8)
water injection well (13)

5-Spot Waterflood Pattern

A single 5-Spot pattern has:

One net producer, and
one net injector, or two total wells
Waterflood Progression

Time 1

Early in life of waterflood. Producer making 100% oil.
Waterflood Progression

Time 2

Still relatively early in life of waterflood. Water banks expanding, but producer still making 100% oil.
Waterflood Progression

Time 3

Mid-life of the waterflood. Water has reached the producing well. Producer now makes oil and water.
Waterflood Progression

Time 4

Late in the life of the waterflood. Producer now making large volume of water compared to the oil volume.
Waterflood Progression

Time 4

Late in the life of the waterflood. Producer now making large volume of water compared to the oil volume.

The effectiveness of the water “sweeping” the area of the pattern is called the “areal sweep efficiency”, or $E_a$.

A waterflood also works in the vertical dimension.....
Permeability

• Permeability, measured in milidarcy’s (md.), is a measurement of a rock’s ability to transmit fluid

• Water injection rate will be a function of permeability

• Most oil reservoirs have multiple layers with varying permeability values
Injection Well

Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8

Producing Well

Oil reservoir with eight layers . . . . .

Injection Well

Layer 1 200 md.
Layer 2 400 md.
Layer 3 50 md.
Layer 4 500 md.
Layer 5 75 md.
Layer 6 100 md.
Layer 7 10 md.
Layer 8 300 md.

Producing Well

. . . . . with variable permeability.

Injection Well Producing Well

Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8

Waterflood – early time

Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8

200 md.
400 md.
50 md.
500 md.
75 md.
100 md.
10 md.
300 md.

Injection Well

Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8

Layer 1: 200 md.
Layer 2: 400 md.
Layer 3: 50 md.
Layer 4: 500 md.
Layer 5: 75 md.
Layer 6: 100 md.
Layer 7: 10 md.
Layer 8: 300 md.

Producing Well

Waterflood – at water breakthrough

Starts to make some water

Waterflood – late life, near abandonment

Injection Well

Producing Well

Producing at a high water to oil ratio (WOR)

Layer 1
200 md.

Layer 2
400 md.

Layer 3
50 md.

Layer 4
500 md.

Layer 5
75 md.

Layer 6
100 md.

Layer 7
10 md.

Layer 8
300 md.
The effectiveness of the water “sweeping” the layers of the reservoir is called the “vertical sweep efficiency”, or $E_v$.
Factors Affecting Waterflood Success

• Timing of flood – earlier is better
  – Higher primary depletion (lower pressure) increases gas saturation
  – High gas saturation decreases oil recovery

• Well spacing
  – Tighter well spacing is better
  – Increases $E_a$ and $E_v$
  – accelerates waterflood recovery

• Pattern selection
  – Balanced patterns improve $E_a$ and WOR performance
Waterflood Recovery Potential

• Should recover an additional 10% to 40% of the reservoir OOIP

• A term commonly used is the secondary to primary ratio (S/P)
  – Primary is the expected ultimate primary oil recovery
  – Secondary is the incremental waterflood recovery
  – S/P ratio of 1+ is generally expected
Types of Oil Reservoirs More Favorable for Waterflood

• Shallow is better
  – Cheaper drilling and operating costs
  – Typically lower primary recovery

• Low energy oil (low $B_o$)
  – Lower primary oil recovery
  – Lower gas saturation

• Higher permeability is better
  – Process the waterflood faster
  – May utilize wider well spacing (cheaper)
Unitization for Waterflooding

• May be needed when reservoir underlies different leases with different ownership

• A waterflood unit combines the leases into a common entity for waterflood operations
  – Allows for more efficient development and operation
  – Maximizes oil recovery

• Requires an “equity formula” to properly compensate all owners
Unitization Example

Lease ‘A’  Lease ‘B’  Lease ‘C’

producing well (8)
water injection well (13)

Unitization in Texas

• “A term frequently used interchangeably with Pooling, but more properly used to denominate the joint operation of all or some portion of a producing reservoir as distinguished from pooling, which term is used to describe the bringing together of small tracts sufficient for the granting of a well permit under applicable spacing rules.

• Williams & Meyers, “Manual of Oil and Gas Terms”
Unitization in Texas

• Unitization DOES NOT require approval of the Texas Railroad Commission.
• Private Units
• “Say No” Boundaries
Unitization in Texas

• Commission approved units must comply with Texas Natural Resources Code Chapter 101 titled “Cooperative Development”
• Statute first passed in 1949
• Not Updated
Unitization in Texas

• Unit Agreement
  – Negotiating the Equity Formula
    • “blue-eyed grandchildren”

• Unit Operating Agreement
MODEL FORM
of
UNIT AGREEMENT
(With Supplement)

AMERICAN PETROLEUM INSTITUTE
Washington, D.C. 20037

Issued by
AMERICAN PETROLEUM INSTITUTE
Production Department
211 N. Ervay, Suite 1700
Dallas TX 75201

Model Form of Statutory Unit Agreement

API MODEL FORM 5U03
SECOND EDITION, JUNE 1, 1983

Model Form of
Voluntary Unit Agreement

API MODEL FORM SU01
FOURTH EDITION, JUNE 1, 1993

American Petroleum Institute
1220 L Street, NW
Washington, DC 20036

Model Form of
Voluntary Unit Operating Agreement

API MODEL FORM 5U02
FOURTH EDITION, JUNE 1, 1999

Unitization in Texas

• Railroad Commission Requirements
  – 65% Royalty Interest Sign-Up to the Unit Agreement
  – 85% Working Interest Sign-up to the Unit Agreement
  – “The Twenty Questions”
    • All interest owners offered to participate on the same yardstick basis
Unitization in Texas

1. Persons entering into and submitting agreement own or control production, leases, royalty or other interests in same field.

2. Agreement was voluntarily entered into (a) to establish pooled units for secondary recovery operations, or (b) to establish pooled unit for conservation and utilization of gas.

3. Agreement is necessary to accomplish purposes in No. 2.

4. Such agreement is in interest of public welfare as reasonably necessary to prevent waste and promote conservation.

5. Rights of all owners in field, whether signing or not, will be protected.
Unitization in Texas

6. Estimated additional cost will not exceed value of additional oil and gas.

7. Other available methods inadequate.

8a. Area covered contains only such part of field as reasonably defined by development.

8b. The owners of interest in the oil and gas under each tract within area reasonably defined by development have been given opportunity to enter into such agreement on same yardstick basis as owners of interests in oil and gas in other tracts in the unit.

9. Unit described in unit agreement sufficient to accomplish purposes of Unitization Act.
Unitization in Texas

10. Such agreement is subject to any valid order, rule, or regulation of the Commission relating to location, spacing, proration, conservation or other matters within the authority of the Commission.

11. Such agreement does not attempt to contain field rules for the area or field.

12. Such agreement does not provide for nor limit the amount of production of oil or gas from the unit properties.

13a. Such agreement does not bind any landowner, royalty owner, lessor, lessee, royalty interest owner or any other person who does not execute same, but binds only the persons who execute it.

13b. No person has been compelled or required to enter into such agreement.

14. Such agreement does not provide directly or indirectly for the cooperative refining of crude petroleum.
15. Such agreement does not provide for the cooperative refining of crude petroleum, condensate, distillate or gas, or any by-produce thereof.
16. Such agreement is not a voluntary agreement for the joint development and operation of jointly-owned properties.
17. Such agreement does not restrict any of the rights which persons now have to make and enter into unitization and pooling agreements.
18a. Such agreement does or does not provide for the location and spacing of input wells and for the extension of leases covering any part of lands committed to the unit.
Unitization in Texas

18b. No such agreement shall relieve any operator from the obligation to develop reasonably the lands and leases as a whole committed thereto.

19. Agreement may provide that the dry gas after extraction of hydrocarbons may be returned to a formation underlying any lands committed to the agreement.

20. When it appears from such agreement or otherwise that ownership of any lands or properties described in such agreement is any party or parties named in Sections 2 and 3 of said Act, the requirements of said Sections of said Act should be complied with.
Unitization in Texas

- House Bill 100 – Taylor
- “Oil and Gas Majority Rights Protection Act”
- Proposed Chapter 104 of TNRC
- “Compulsory Unitization”
  - 70% Royalty Interest Sign-Up
  - 70% Working Interest Sign-up
  - Applies to
    - Repressuring
    - Waterflooding
    - Pressure Maintenance
    - Tertiary recovery operations
    - Any other similar operations
- Commission may investigate the soundness of the equity formula (remember the “blue-eyed grandchildren”)

# Unit Tract Participation Factors - Example

<table>
<thead>
<tr>
<th>Tract</th>
<th>Lease</th>
<th>Tract Participation</th>
<th>Surface acres</th>
<th>OOIP MSTB</th>
<th>current BOPD</th>
<th>useable wells</th>
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</thead>
<tbody>
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<td>1</td>
<td>Lease 'A'</td>
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<td>200</td>
<td>2,100</td>
<td>31</td>
<td>6</td>
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<td>0.28827399</td>
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<td>1,600</td>
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<td>7</td>
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<tr>
<td>3</td>
<td>Lease 'C'</td>
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<td>2,500</td>
<td>74</td>
<td>8</td>
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<tr>
<td>TOTALS</td>
<td></td>
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<td>520</td>
<td>6,200</td>
<td>157</td>
<td>21</td>
</tr>
</tbody>
</table>

TOTAL > 1.000
# Lease 'A' Ownership

<table>
<thead>
<tr>
<th>Owner</th>
<th>Net Rev. Interest</th>
<th>Tract Participation</th>
<th>Unit Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Operating, Inc.</td>
<td>0.750000</td>
<td>0.281498</td>
<td>0.211123</td>
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<td>John Geologist</td>
<td>0.050000</td>
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<td>0.014075</td>
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<tr>
<td>James Farmer</td>
<td>0.120000</td>
<td>0.281498</td>
<td>0.033780</td>
</tr>
<tr>
<td>Edith Farmer</td>
<td>0.080000</td>
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<td>0.022520</td>
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</tbody>
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