What’s Wrong With My Waterflood???

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TOPICS

• Waterflooding is a secondary oil recovery process
  – follows “primary”, solution gas drive recovery
  – therefore a “secondary” recovery process

• Ideal waterflood reservoir conditions

• Waterflood recovery factors

• Common problems with waterflood performance
Waterflooding as a Recovery Process

- Recognized enhanced oil recovery technique since the early 1900’s
- Pennsylvania
  - Accidental waterflood ~ 1890’s
  - Illegal waterflooding ~ 1910’s
  - Legalized waterflooding ~ 1921
- Oklahoma early 1931
- Texas, Kansas, New York, and California were also early players
Ideal Waterflood Properties

Rock Properties
• Shallow (cheap)
• High perm
• Low perm variation
• High porosity
• High rock continuity at current well spacing
• Low residual oil saturation

Fluid Properties
• Higher API gravity
  – Lower viscosity
  – Lower mobility ratio
  – Improved areal sweep
• Low energy (low GOR)
  – Low bubble point Press.
  – Low primary recovery
  – Lower Sg at depletion
  – Higher S/P ratio
Waterflood Recovery Factors

- **Primary oil recovery factors typically range** from about 5% to 20% OOIP for solution gas drive reservoirs
- **Waterflood recovery factor**
  - *Primary + Secondary recovery*
  - *Generally 20% to 40%+ OOIP*
- **Secondary/Primary (S/P) ratio**
  - *Generally ranges from 0.5 to 2.0+
  - *Generally higher for lower energy oil*
Two Typical Waterflood Problems

1. *Longer than expected response time*
2. *Early water breakthrough*
PROBLEM 1

LONG RESPONSE TIME
Long Response Time

1. High gas saturation
2. Low injector/producer ratio
3. Low injectivity (low perm)
4. Poor injection efficiency
Long Response Time

1. High gas saturation
   - Probably most common reason
   - We’ll spend most of our time here

2. Low injector/producer ratio

3. Random pattern (or no pattern)

4. Low injectivity

5. Poor injection efficiency
1. High Gas Saturation (Sg)

- Higher primary depletion (lower BHP) leads to higher gas saturation (Sg), but does depend on Pbp
- High gas saturation leads to:
  - Large “fillup” volume
  - Lengthy fillup time
  - Early water breakthrough
  - Reduced waterflood oil recovery
- Example gas saturation calculation….
Gas Saturation

Oil and gas saturations at start of injection:

\[ So = (1 - Swc) \times (1 - Erb) \times \left( \frac{Bo}{Bob} \right) \]

\[ Sg = 1 - Swc - So \]

Where:

- So = oil saturation, fraction PV
- Sg = gas saturation, fraction PV
- Swc = connate water saturation, fraction PV
- Erb = oil recovery from bubble point, fraction OOIP
- Bo = current oil FVF, RB/STB
- Bob = oil FVF at bubble point, RB/STB
Gas Saturation (Sg)

• Sg is a function of depletion (BHP) below the system bubble point pressure

• Following graph is for an oil with moderate properties
  – $R_{si} \sim 750 \text{ scf/STB}$
  – $Bo_i = 1.40$
40 Acre 5-Spot Pattern Simulation Model

- Gas saturation
- S/P ratio

BHP at start of waterflood - psi

40 Acre 5-Spot Pattern Simulation Model

- S/P Ratio
- %OOIP

BHP at 1st Injection - psi

EUR as %OOIP

- < 25%
- 40%+

Gas Saturation (Sg)

• Sg is a function of depletion (BHP)
• But many times, BHP is unknown
• Cumulative oil production can be used as a “proxy” for BHP depletion:

Depletion = Cum. oil / primary EUR
40 Acre 5-Spot Pattern Simulation Model

depletion

Cum. oil / primary EUR

gas saturation - %PV
40 Acre 5-Spot Pattern Simulation Model

Cum. oil / primary EUR

S/P Ratio

depletion
40 Acre 5-Spot Pattern Simulation Model

Long Response Time

1. High gas saturation

2. Low injector/producer ratio

3. Low injectivity (low perm)

4. Poor injection efficiency
2. Low Injector/Producer Ratio

- Extends gas fillup time
- May need to convert more wells to injection
- Re-configure or fully develop the waterflood pattern
- Example
  - use a 9-spot versus a 5-spot pattern
  - Next slide…
Five Spot Pattern

1:1 injector to producer ratio

normal

1:1 injector to producer ratio

inverted
Nine Spot Pattern

3:1 injector to producer ratio

1:3 injector to producer ratio

normal

inverted
Long Response Time

1. High gas saturation
2. Low injector/producer ratio
3. Low injectivity (low perm)
4. Poor injection efficiency
3. Low Injectivity

• May be due to low permeability
  – May be addressed with well stimulation
    • Acid or small frac
  – Only solution may be infill drilling

• Could be due to poor rock continuity
  – Again, only solution is infill drilling
Long Response Time

1. High gas saturation
2. Low injector/producer ratio
3. Low injectivity (low perm)
4. Poor injection efficiency
4. Poor Injection Efficiency

• **Loss of some of the injection water out of zone**
  – Very common, happens in most floods

• **Potential causes**
  – Poor cement jobs
  – Excessive injection pressure
    • Surface pressure
    • Bottom hole injection gradient

• **Should run periodic injection profile surveys to monitor injection operations**
PROBLEM 2

PREMATURE WATER BREAKTHROUGH
Early Water Breakthrough

• Possible directional permeability
• Poor mobility ratio (‘M’)
• High permeability variation
• High gas saturation (discussed earlier)
• Large hydraulic fractures oriented from injector to producer
Early Water Breakthrough

• Possible directional permeability
• Poor mobility ratio (‘M’)
• **High permeability variation**
  – Dykstra-Parsons ‘V’ factor
• High gas saturation
• Large hydraulic fractures oriented from injector to producer
Dykstra-Parsons ‘V’ Factor

- Calculated from core data
- ‘V’ factor is a measure of perm variation
  - Lower slope (‘V’) > less perm variation
  - Higher slope (‘V’) > more perm variation
- Theoretical range for ‘V’
  - Zero for equal value perm’s – no variation
  - Approaches 1.0 for extreme variation
- Practical, “real world” range for ‘V’
  - Close to 0.5 for very homogeneous sand (E TX Woodbine)
  - ‘V’ = 0.90+ for some West Texas carbonates
EXAMPLE DYKSTRA-PARSONS PLOT

V-Factor = 0.65
K-mean = 4.5 md

Max. Perm = 68 md; 154 Perm Data

Data
Log Normal Distribution
20-Layer Model
20-Layer Dataset
EXAMPLE DYKSTRA-PARSONS PLOT

V-Factor = 0.80
Kmean = 13.0 md
Max. Perm = 281 md; 50 Perm Data

PERMEABILITY, md

CUMULATIVE PROBABILITY (PERCENT EQUAL TO OR GREATER THAN)
EXAMPLE DYKSTRA-PARSONS PLOT

V-Factor = 0.92
Kmean = 36.0 md
Max. Perm = 2,320 md; 36 Perm Data

CUMULATIVE PROBABILITY (PERCENT EQUAL TO OR GREATER THAN)

Data
Log Normal Distribution
20-Layer Model
20-Layer Dataset

40 Acre 5-Spot Pattern Model

Results at ~97% W/C: S/P = 0.522, S/P = 0.862, S/P = 1.194
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