Moving from Secondary to Tertiary Recovery Stages

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Outline

• Reservoir Data
• Geologic Data
• Formation Data
• Fluid Data
• Primary & Secondary Performance
• EOR Development
• Closing
This is a Workshop open for Discussion
Reservoir Data

- Total Surface Area, AC: no. of wells, pattern
- Well Spacing, AC: < 80 acre spacing
- Average Net Pay: thin vs. thick
- Type Primary Producing Drive: solution gas drive, fluid expansion, waterdrive
- Depth: Injection Pressure
- Temperature
Geologic Data

- Formation:
- Type (Sandstone/Carbonate): clean vs dirty sandstone, fractured carbonate; dual porosity
- Reservoir Structure
- Reservoir Isopach
- Faults, Compartmentalization, Unconformities
Formation Data

• Porosity, % (Avg. & Range):
• Permeability Average md:
• Permeability Range, md:
• Permeability Variation, Kv:
• Wettability
• Clays
• Fractures (Y/N)
Dykstra-Parsons Permeability Variation

\[ K_v = k_{avg} - k_\sigma \]
\[ k_{avg} \]

\[ K_v = 230 - 70 \]
\[ 230 \]

\[ K_v = 0.7 \]
Waterflood Oil Recovery

Fluid Distribution During Waterflood of Water-Wet Rock

- Early in Drive
- Midway in Drive
- Flood-out

Fluid Distribution During Waterflood of Oil-Wet Rock

- Early in Drive
- Midway in Drive
- Economic Limit
Displacement Efficiency

Oil Displacement by Water, Oil-wet Sand

Oil Displacement by Water, Water-wet Sand

Enhanced Oil Recovery Institute
Core Treatment Parameters

• Kf / Ki
  - Final permeability / initial permeability

• (Kf / Ki) t
  - Treatment-induced permeability damage

• (Kf / Ki) s
  - Fresh water sensitivity after treatment

• (Kf / Ki) c
  - Fresh water sensitivity for a comparable untreated plug
Core Results

185° F – Oligocene Aged Sandstone

Crude

Prod. Water

Core Results
Fluid Data

- Oil Properties
  - Gravity
  - Viscosity
  - Formation Volume Factor
  - Relative Permeability
- Water Properties
  - Salinity
  - Connate Water Saturation
  - Hardness
  - Relative Permeability
- Mobility Ratio
Typical Water-Oil Relative Permeability Characteristics

**Strongly Water-Wet Rock**

- **Water**: Generally has a lower relative permeability compared to oil.
- **Oil**: Typically shows a higher relative permeability.

**Strongly Oil-Wet Rock**

- **Water**: Usually has a higher relative permeability compared to oil.
- **Oil**: Generally exhibits a lower relative permeability.
Fractional Flow Curves

**Strongly Water-Wet Rock**
\[ \mu_o = 1 \text{ cp}, \mu_w = 0.5 \text{ cp} \]

**Strongly Oil-Wet Rock**
\[ \mu_o = 1 \text{ cp}, \mu_w = 0.5 \text{ cp} \]
Mobility Ratio (M)

• A ratio of the water mobility in the “water bank” to the oil mobility in the “oil bank”

• \[ M = \frac{K_{rw}/\mu_w}{K_{ro}/\mu_o} \]

• Use end point relative permeability
Effect of Permeability Variation $& M$ on Sweep Efficiency – WOR = 1.0
Primary & Secondary Performance

Primary Producing Mechanism

• Fluid Expansion
• Solution Gas Drive
• Oil Recovery % OOIP; 3-20% OOIP; Waterdrive ->30% OOIP
• Time Rate Production Curve
Primary Production

Primary Decline Curves

- Decline 1
- Decline 2
- Decline 3
Total Field Production

Monthly Production & Conc (mg/L)

- May 86
- Aug 87
- Dec 88
- May 89
- Aug 90
- Sept 91
- Jan 93

- BOPM
- BWPM
Primary & Secondary Performance

Secondary Recovery Performance

• Oil Response
• Water Breakthrough
• Oil Recovery % OOIP
• Injection Well Performance
• Production/Injection Issues
  • Water Quality - scale, bacterial, etc.
  • Production - fluid levels, total fluid changes

• Well Integrity
Waterflood Patterns

Two-Spot

Three-Spot

Regular Four-Spot

Skewed Four-Spot

Five-Spot

Direct Line Drive

Staggered Line Drive

Seven-Spot

Inverted Seven-Spot

Normal Nine-Spot

Inverted Nine-Spot
Hall Plot – Injection

Typical Hall Slopes

Cumulative Pressure (PSI x Days/BBL)

Cumulative Water Injection (BBLs)
Hall Plot Curve Shapes
EOR Development

Address Issues Limiting Waterflood Recovery

• Water Issues
• Spacing
• Injectivity Limitations
• Sweep
• High Residual Oil Saturation
Waterflood Oil Recovery

\[ N_P = \text{OOIP} \times E_D \times E_{AS} \times E_{VS} \]

- \( N_P \): Waterflood oil recovery
- \( E_D \): Displacement efficiency
- \( E_{AS} \): Aerial sweep efficiency
- \( E_{VS} \): Vertical sweep efficiency
Water Quality

- Filter injection water
- Monitor, Monitor, Monitor!
  - Salinity changes
  - Solids content
  - Scale formation
  - Corrosion
  - Bacteria
Cambridge Field Pilot Test Results

Oil Production

- Primary
- History Match Primary
- Forecast Secondary ASP Flood
- Alkaline-Surfactant-Polymer Flood

- Actual
- Simulated
EOR Development

Design EOR Process to Maximize Efficiency, Oil Recovery & Economics

- Waterflood Issues to Address
- Facility Design
- Personnel
To have a successful EOR Project, everything that is necessary for a successful waterflood is required with the integration of the EOR process in the reservoir coupled with proper surface facilities.