Basic Screening Decisions for Considering EOR Projects

Charlie Carlisle - Chemical Tracers Inc.
Glen Murrell - EORI

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Typical EOR Implementation Approach

Lab Core Flood Evaluation
- 3-6 Months Work
- Scale; PV < 250 milliliters (0.001 bbls)
- Cost ~ $200K
- Justification: Essential Screening Step

Single 5-Spot, (or More) Pattern
- 3-5 Years Work
- Scale; PV ~ 500,000 bbls
- Cost ~ $10MM-$20MM
- Justification: Oil in Tank
  In-Situ Test
  Reduce Further Risk

Field Wide or Expanded Flood Pattern
- 5-15 Years Work
- Scale; PV ~ 10MM to >100MM bbls
- Risk ~ $100MM-$400MM
- Justification: Additional OOIP Recovery
Better EOR Implementation Approach

Lab Core Flood Evaluation

- Single 5-Spot, (or More) Pattern
- Porosity = 0.25 Oil
- One Month of Work
- Scale; PV ~ 1,000 bbls
- Cost ~ $150-200K
- Justification: Establish EOR Target Oil
- EOR Injectivity Test
- In-Situ Demonstration
- Reduce Further Risk

SWCT One-Spot-Pilot

Field Wide or Expanded Flood Pattern
Recent Field Projects Carried out by Chemical Tracers, Inc.
SWCT One-Spot Pilots Have Successfully Evaluated:

- ASP (12)
- Lignin-Surfactant-Polymer (2)
- Surfactant-Polymer (9)
- Lo-Sal Water Flood (62)
- Miscible Hydrocarbon / WAG (5)
- Carbon Dioxide (8)
Why is only 1/3 of the original oil in place typically recovered?

Recovery Efficiency RE = \( D_e \times A_s \times V_s \)

A typical EOR project might have \( RE = 0.9 \times 0.7 \times 0.8 = 0.5 \), or 50% of the remaining in place.
Polymer
WHY IS ONLY 1/3 OF THE ORIGINAL OIL IN PLACE TYPICALLY RECOVERED?

Microscopic Displacement Efficiency $D_e$

Areal Sweep Efficiency $A_s$

Vertical Sweep Efficiency $V_s$

Recovery Efficiency $RE = D_e \times A_s \times V_s$

A typical EOR project might have $RE = .9 \times .7 \times .8 = .5$, or 50% of the remaining in place.

Slide Courtesy Gene DeBons, Reservoir Solutions, Inc.
Example of Viscosity of High Molecular Weight Polymer (SNF FP3630S)

Graph courtesy of Dr. Gary Pope
Buckley-Leverett Example
Permeability and polymer MW

- 50 mD to 250 mD \rightarrow 4 to 6 MDa
- 200 mD to 400 mD \rightarrow 6 to 8 MDa
- 400 mD to 600 mD \rightarrow 10 to 12 MDa
- 500 mD to 1+ Darcy \rightarrow 12 MDa and above

Courtesy of Jim Dillard, SNF
ASP

(Chemical Flooding, AP, SP etc etc)
WHY IS ONLY 1/3 OF THE ORIGINAL OIL IN PLACE TYPICALLY RECOVERED?

Recovery Efficiency \( RE = D_e \times A_s \times V_s \)

A typical EOR project might have \( RE = 0.9 \times 0.7 \times 0.8 = 0.5 \), or 50% of the remaining in place.
Capillary Desaturation Curve

\[ N_c = \frac{V \mu}{\sigma} \]

Alton and Hilfer, 1999, Sandstone Data
Capillary Number

\[ N_c = \frac{V\mu}{\sigma} \]

Where:
\( N_c \) = Dimensionless capillary number
\( V \) = Velocity of fluid (Superficial or Darcy Velocity), cm/sec.
\( \mu \) = Viscosity of injectant, poise (dyne-sec./cm\(^2\))
\( \sigma \) = Interfacial Tension of oil/water at Sor (dynes/cm)

Darcy Velocity, \( V \) is:

\[ V = \frac{Q}{2\pi RH} \]

Where:
\( V \) = Darcy Velocity, cm/sec.
\( Q \) = Injection rate, cc/sec
\( R \) = Radius where velocity is considered.
\( H \) = Height of injection interval, cm.
Matching the Surfactant to the Oil

Surfactants with an equal attraction to the oil and water are optimum

Graph courtesy of Dr. Gary Pope
Salinities from Representative Oilfield Brines….

slide courtesy of Gary Pope, UT
Natural Competing Reactions For Soda Ash
Eliminate the Alkaline Benefit and Generate Precipitates

\[
\text{Na}_2\text{CO}_3 + \text{Ca}(\text{R}) \rightarrow \text{CaCO}_3 \downarrow + \text{Na}_2(\text{R})
\]
Soda Ash

\[
\text{Na}_2\text{CO}_3 + \text{Mg}(\text{R}) \rightarrow \text{MgCO}_3 \downarrow + \text{Na}_2(\text{R})
\]
Soda Ash

\text{R can be CO}_3, \text{SO}_4 \text{ or a host of other anions}

But…

Carbonate (CO}_3\text{) and anhydrite (SO}_4\text{) are the main players.
Calcium Sulfate, Anhydrite, Presence Eliminates The ASP Option

Anhydrite Cementing

Slide Courtesy of Peigui Yin, EORI
CO₂
Recovery Efficiency $RE = D_e \times A_s \times V_s$

A typical EOR project might have $RE = 0.9 \times 0.7 \times 0.8 = 0.5$, or 50% of the remaining in place.
WHY CO$_2$?

- Miscible at lower pressures than nitrogen or methane
- Cheaper and more plentiful than LPG/enriched hydrocarbon gas
- Density (in dense phase) closer to reservoir fluids - oil/water
KEY (MINIMUM) REQUIREMENTS FOR CO$_2$ MISCELLANEOUS PROJECTS

- MISCELLANEOUS
- TEMPERATURE/ PRESSURE
- DEPTH
- OIL CHARACTERISTICS
  - API GRAVITY
  - VISCOSITY
  - COMPOSITION
- CORRELATIONS

Slide Courtesy of Melzer Consulting
MISCIBILITY CONCEPTS

MINIMUM MISCIBILITY PRESSURE
SLIMTUBE TEST

OIL RECOVERY - % OOIP

PRESSURE - PSIG

MMP

Nitrogen

Slide Courtesy of Melzer Consulting
ESTIMATING CO₂ MMP

YELLIG AND METCALF* METHOD FOR ESTIMATING CO₂ MMP

MMP in PSIG

MMP LAB DATA
Y&M

MMP = 12.4*Tf - 60

TEMPERATURE in DEG F

0 500 1000 1500 2000 2500 3000

0 60 80 100 120 140 160 180 200

* Ref: JPT 1/80

Slide Courtesy of Melzer Consulting
Screening and Decision Making
Decision making under uncertainty
  • Our objective is to reduce uncertainty

3 methods
  1. Enhance knowledge (Geo. and Eng. studies, data acquisition)
  2. Simplify Decision (Screening)
      • Decision is not “Shall we CO2 flood?” but “Is there a reason why we should no longer consider it?”
      • Allows us to assess variables, and their uncertainties, individually
          • For example, “Should we do a CO2 flood?” requires many variables to be assessed collectively (e.g. in a NPV calculation) and all the uncertainties will propagate through to the calculation and make it meaningless. Compare with “Is the density of our oil too high to do a CO2 flood?”; “Is reservoir too shallow?”; “Is it too hot?” where each variable and its uncertainty is assessed individually.
  3. Reduce no. of Variables
      • Easily determined variables for which there are well understood, fundamentally derived decision criteria

• Many operators do not have the data-set for 2. or the means for 1.
Deal-Breakers

**Polymer**
- < 50mD perm (Molecular size)
- Res. Temp > 200°F (Polymer stability)

**ASP**
- Anhydrite present (For ASP and AP)
- Salinity > 100K ppm (Solubilization)
- Res. Temp > 200°F (Molecular stability)

**CO₂**
- Depth < 2,000 ft (MMP > FP)
- Reservoir Pressure < 1,500 psi (Need to re-pressurize)
‘Other’ issues

**Polymer**
- $S_{or}$
- Salinity (ppm $\uparrow$; $\$$ $\uparrow$)

**ASP** (Chem. Flooding, AP)
- Complex System
- Surfactant Retention (for ASP and SP)

**CO$_2$**
- CapEx
- Supply
- WF Performance (viscous fingering)
Conclusions

• EOR addresses recovery efficiency problems at micro- and macroscopic scales
• Decisions regarding EOR options hinge on availability of information
• Methods such as Polymer, ASP and CO₂ Misc have ‘deal-breaker’ criteria that can be easily assessed and require little information.
Thank you