Advanced Recovery in Unconventional Reservoirs

Luncheon Keynote by

Todd Hoffman

Montana Tech

25th Annual CO₂ Conference

Thursday Dec 12th, 2019
Outline

• Overview of EOR in Unconventional Reservoirs

• Potential Issues/Pitfalls – Things to consider

• Economics & Investments
Unconventional Reservoirs

also known as (aka)

• Shale Oil / Shale Gas
• Resource Reservoirs
• Source Rock Reservoirs
• Light Tight Oil (LTO)

Characteristics

– Source rock & reservoir rock are the same or nearby
– Extremely low permeability
– Requires long horizontal wells and multi-stage hydraulic fracturing
Elm Coulee Bakken (Montana)


(EIA, 2011)
Bakken – Expanded Development

• In late 2000’s, development expanded to North Dakota side of the Bakken
Eagle Ford - Development

- Eagle Ford development exploded in early 2010’s

- Oil Wells
- Gas Wells
- Permitted Wells

(TRC, 2015)
Unconventional Oil Reservoirs

North America Formations
• Bakken
• Eagle Ford
• Niobrara/Codell
• Utica
• Montney
• Permian
• STACK/SCOOP
• Duvernay
• others …
Increased oil rate in the US is from unconventional oil reservoirs

- Trillions of barrels of oil resource in unconventional reservoirs

Unconventional Oil Success - US

(EIA, 2019)
Unconventional Oil Opportunities

- High initial rates, but rapid decline
- Low recovery factors (5-10%)

Average Eagle Ford Oil Production

- Need for EOR in unconventionals is apparent
Options for EOR in Unconventionals

**Gas**
- CO$_2$
  - Source may be issue
- Rich natural gas
  - 60% C$_1$, 40% C$_2$+
  - Behaves similar to CO$_2$
- Lean natural gas
  - 90+% C$_1$, <10% C$_2$+
  - Vapor extraction
- Miscible / Immiscible

**Water / Surfactants**
- Injectivity doesn’t appear to be a concern
- Matrix imbibition
- Surfactants may help
  - Change wettability
  - Find low cost option?
- Low salinity
Initial Simulation Study - Bakken

- 4 Sections (2 mi. x 2 mi.)
- 8 layers including upper shale and middle member
- Multiple CO$_2$ injection cases

- Simple model
- Indicates added recovery

Grad student at Montana Tech
Summer intern at Continental
(Shoaib, 2009) SPE 123176
Early Pilots - CO₂ Injectivity - Bakken

➢ 2 Pilot tests (one in MT and one in ND)
➢ Injection rates / pressures
  • ~1500 Mscf/day @ 2000-3000 psi
  • 30-45 days inj., 10-20 days soak, ~ 3 months prod.

Hoffman & Evans, 2016
EOR in UR - Research

- Laboratory / Experiments
  - Gas Injection
  - Surfactants
- Analytical Analysis
- Reservoir Modeling / Flow Simulation
  - Generally, models showed success
  - Capturing true EOR response?
EOR Pilots in the Bakken

9 pilots in MT/ND Bakken
- 3 in MT and 6 in ND

5 Gas
- 3 CO₂
- 2 Natural Gas

4 Water (1 with surfactants)
Continuous Water Injection – Bakken Pilot

Injection rates
- ~1350 bbl/day for 8 months
- then shut in for 6 months
- ~380 bbl/day for 8 months
Continuous Natural Gas Injection - Pilot

➢ Injection rates
  • ~1700 Mscf/day for 2 months

➢ Most encouraging of Bakken pilots
  • All wells have increased oil production (2 wells complicated by frac hits)

Also looked at offset wells North and South of injection well
Injection Pilot - Flow Simulation Model

History Matching Results

Average properties

\[ H = 33 \text{ ft} \quad k_H = 0.023 \text{ md} \]
\[ \phi = 4.3 \% \quad k_V = 0.023 \text{ md} \]

- Hydraulic fractures modeled in dual porosity grid

\[ \phi_f = 0.01 \% \quad k_f = 50 \text{ md} \]
Injection Pilot - Prediction Cases

- Continuous vs. Huff-n-Puff
- Water vs. Natural Gas
- Injection Rate Sensitivity
- Cycle Change Frequency

Huff-n-Puff :: ~20% better than primary
Continuous :: ~20% worse than primary
Injection Pilot - Surfactants

- Surfactant Concentration
  - ~1500 ppm
  - Low salinity brine

- 2 weeks of injection
- 4 months shut in (soak)

- Oil rate increased from ~80 bbl/d to 180 bbl/d
- Sustained for 1.5 years so far ...
- Increase EUR by 25%

SPE 190172
EOR Pilot Tests - Eagle Ford

- 12+ pilots in Eagle Ford
- 5+ operators
- All huff-n-puff operations with hydrocarbon gas inj.

★ Pilot locations
Eagle Ford - Huff-n-Puff EOR

- Reported in investor relations presentation
- But no data presented

- Started at end of 2012
- Lean gas Inj. (90-95% C₁)
- 3 cycles in 2013
Multi-Well - Huff-n-Puff EOR

• ~ ½ wells injecting (4/8 in Pilot B, 6/14 in Pilot C)
• Increase in oil production is evident

[Graphs showing total lease oil production rate with labeled data points and comparison of 1065 b/d vs. 420 b/d.]
Eagle Ford Huff-n-Puff Pilot D: 4 Wells

- 4 isolated wells
  - injecting/producing in all
- Cleanest indication of improved recovery

- After 3 years of injection, recovery is more than 30% greater than primary
Eagle Ford Summary

- EOG is at 150+ wells with Huff-n-puff gas injection
- At least 4 other companies have injected in EF, and many more are planning pilots
- Early indications look promising, but issues? …
Other Basins

- DJ Basin / Niobrara
- SCOOP in OK
- Montney (future?)
- Others…
- Permian (next slide)
Permian

- Permian
- Chevron
- Laredo / GTI
- EP Energy
- Oxy
  - Delaware Basin (2 NM)
  - Midland Basin

★ Pilot locations
Potential Issues/Pitfalls – Lessons Learned

- Conformance Control
  - Building Pressure
  - Shutting off ‘Big Water’
- Importance of the Primary Completion
- Compressors/Equipment
- Access to Gas
- Land Issues
- Injection Implementation
Building Pressure

- Force gas to go back into solution
  - Miscibility Pressure (kind of...)

Aside
- Black Oil v. Gas Condensate
Conformance Control – Bakken

- Difficult to build pressure
- Initial compressor too small
- Wells had low pressure (depleted)
- Pressure leaked off to offset wells

MB: Middle Bakken
UTF: Upper Three Forks

440 ft
880 ft

Larena/ Leon Pad

Leon 1MBH
Leon 2MBH
Larena MB
Leon 3TFH
Leon 4MBH
Golrick 5MBH
Golrick 6MBH
Golrick 6MBH
ND State 10TFH

T158N-R95W-Sec8/17

3TFH – Well that built highest pressure. But did not reach miscibility pressure.

(NDIC, 2019)
Conformance Control – Eagle Ford

- Model required fractures crossing all 9 wells to match breakthrough
  - Had to shut wells in to prevent gas breakthrough
  - Gas leakage was a major issue

- Possible Solutions: Isolate cluster of wells, pressure containment strategies.
Importance of Primary Completion

1. Lots of surface area (10-100 million ft$^2$)
   - Better for primary, too

2. Not intersecting with offset wells
Compressors

- Get the most amount of gas in the ground with shortest shut-in times, above miscibility pressure
Compressors & Equipment

Compressors
- Huge Machines
  - 6000-9000 psi outlet pressure
  - 5-15 Million SCF/day outputs
- Largest Expense
  - Multi-million dollars
  - Maximize usage (>1 pattern)
- Delivery Date
  - 6-9 months out (coming down)

Other Equipment
- Wellhead (5K enough)
- Gas-tight tubing connections
- Packers, etc.
- Gas handling
  - Existing equipment sizes
  - Sour gas
Access to Gas / Land Issues

Gas
- Slowed and stopped projects
- Produced gas often is not enough
- Compressors need 1000 psi suction pressure
  - Booster compressor or line pressure

Land
- Slowed and stopped projects
- Need buy-in from royalty owners, lease partners, & offset acreage operators
- Allocate gas: state for taxes & royalty owners
  - Need industry consistency
Injection Implementation

- CO$_2$ vs. Natural Gas vs. Water
- Continuous vs. Cyclic (Huff-n-Puff)

Nechelik Field, Alaska

- Longitudinal Fracs
- Perm. ~0.1 - 1 md
- Continuous WAG Injection Scheme
Economic Analysis and Investments

• Eagle Ford Economic Example

• Added Value

• Comments
Eagle Ford Economic Analysis

- Predictions are based on extrapolating decline curves
- Inject 2 months; produce 2 mo.

- Predicted out for 20 years
- Similar to reported expected recoveries (1.3x - 1.7x)
Eagle Ford Economic Analysis

Inputs

- **CapEx**: $1 million/well
  - compressors, flowlines, workovers, etc.
- **Injection rate**: 2 million scf/day ($2.50/Mscf)
  - 3 month fill up time
  - 20% make up gas during injection time
- **OpEx**: 10% of injected gas – compressor fuel
- **20 year predictions - Discount rate**: 15%

Results

<table>
<thead>
<tr>
<th>Oil Price</th>
<th>$35</th>
<th>$50</th>
<th>$65</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV</td>
<td>-$1,300,000</td>
<td>$1,700,000</td>
<td>$4,700,000</td>
</tr>
<tr>
<td>IRR</td>
<td>-- %</td>
<td>28.1 %</td>
<td>44.1 %</td>
</tr>
<tr>
<td>Payback</td>
<td>-- yrs</td>
<td>1.8 yrs</td>
<td>1.2 yrs</td>
</tr>
</tbody>
</table>

**Comments**

- Marginally economic
- More than half of the cost is gas fill up
- Efficiency gains should be realized over time
Upside Potential

Lifecycle of Unconventional Wells

1. Acreage costs: ~$1-4 million / well

2. Well construction costs: ~$5-8 million / well

3. Primary Production: if EUR is ~300,000 STB, ~$15-18 million, with opex and time value, marginal well

4. EOR Production: if EUR goes to ~450,000 STB for ~$1 million in capex and ~$1 million in gas costs, that can improve the economics*

*some companies in EF are adding EOR production in private equity proposals
Economics of EOR in Unconventionals

• Operational efficiencies will improve economics
• Start injection earlier, but after some depletion (~1 yr)
• May not be as economic as new drills in Tier 1 acreage (but on par with Tier 2 acreage)
• Other EOR methods may be more economic
• Knowledge from pilots is essential to increasing profitability
Conclusions

• Potential is Enormous for EOR in Unconventionals
  – Huge volumes in place; Low recovery factor

• Natural gas huff-n-puff works wells in Eagle Ford
  – Large scale field development is occurring

• Other basins still in testing period
  – e.g Permian, Bakken, SCOOP, Niobrara …

• Ultimately, other methods may prove to be better
  – Water, CO$_2$, surfactants, continuous injection, etc.

• Significant work to be done
  – Lab, modeling, and field trials
Questions/Comments

Thank you!

Contact information:
Todd Hoffman
thoffman@mtech.edu

25th Annual CO₂ Conference