Oil Recovery from Bakken Shale by Miscible CO_2 Injection

2016 SCCS Annual Meeting

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5/11/2016

Agenda

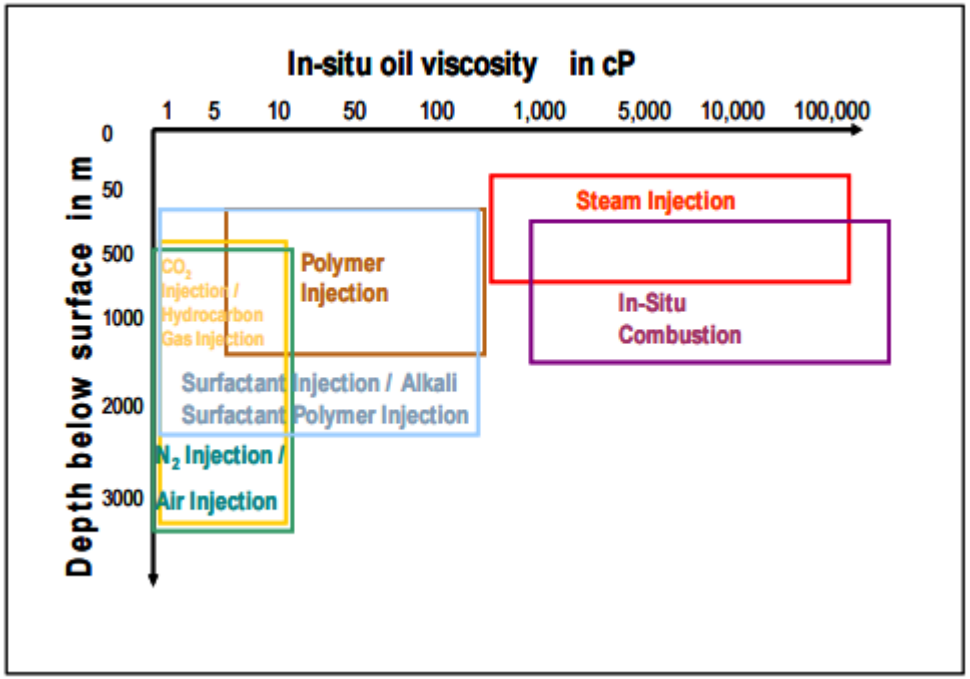
- Project motivation & objective
- Miscible CO_2 EOR
- Coreflood experiments with tomographic imaging
- Simulation of miscible CO_2 injection
- Future work

Project Motivation

- One of the most productive tight oil plays in North America
  - Technically recoverable oil: 7.4 billion STB
- Low primary recovery factor: 5 to 10%
  - Rapid decline in production after initial peak
- EOR is a necessary step to efficiently explore unconventional liquids-rich reservoirs

Choice of EOR Technique for Bakken

- Reservoir depth: ~9,000 to 10,500 ft (2,743 to 3,200 m)
- Oil viscosity: 0.15 – 0.45 cP @ Reservoir Conditions
- Light crude oil from 36 to 48 º API
- Reservoir temperature: 150 to 240 ºF
- Reservoir pressure: > 4,000 psi



Source: Poellitzer, et al., 2009 (SPE 120991)

Project Objective

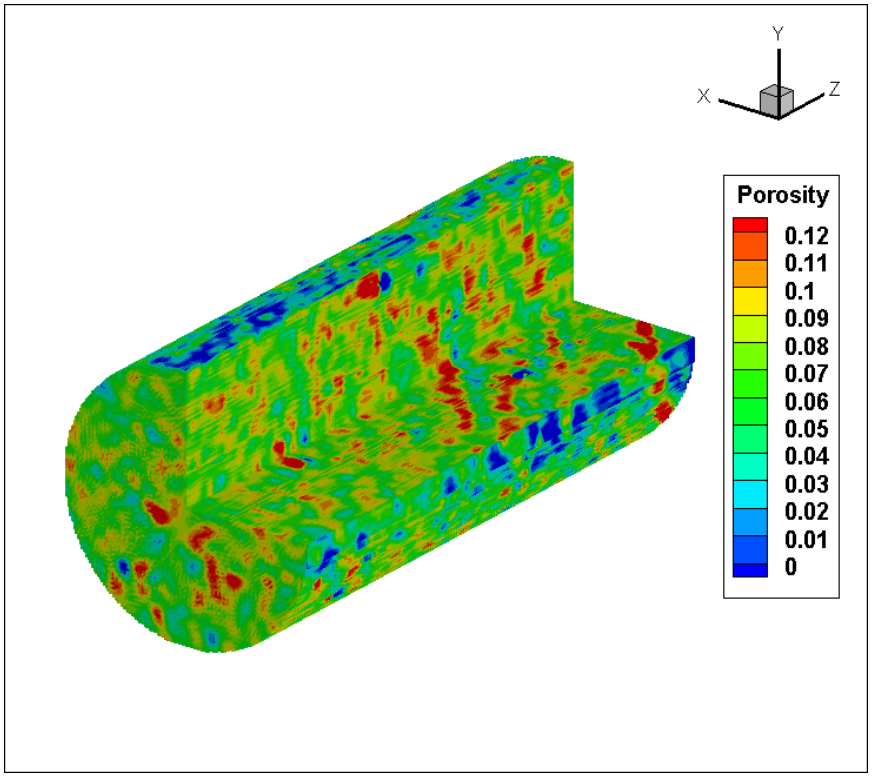
- Conduct coreflood experiments to quantify recovery potentials of continuous CO_2 drive at miscible conditions

- Apply X-ray Computed Tomography (CT) technique to visualize fluid flow at core level
  - Dual-energy scan at 140 keV and 80 keV

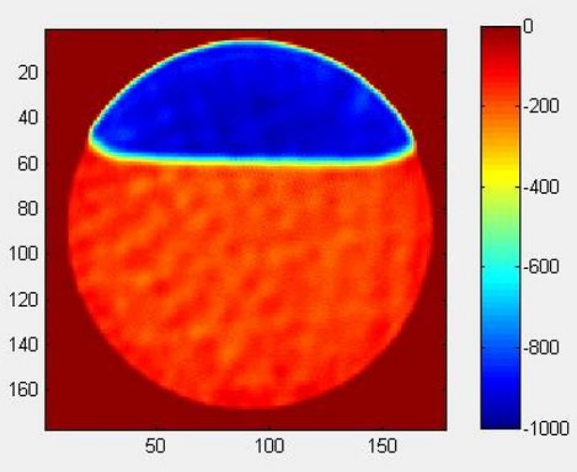
- Model the CO_2 injection process to reproduce experimental results

Core Sample Specification

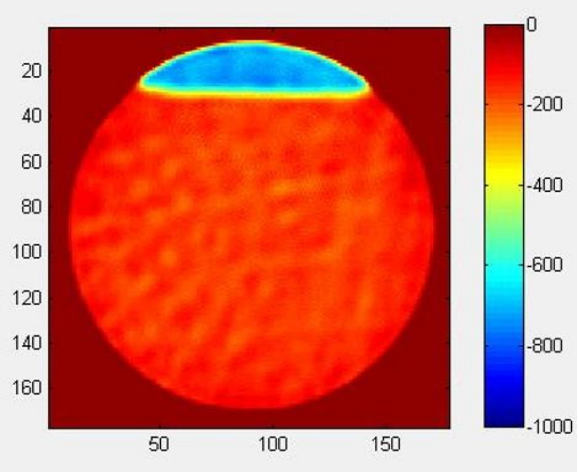
- 1'' diameter, 2'' length
- Permeability (with oil): 1.8 µd
- Average porosity: 7.5%
- Pore volume: ~2 mL



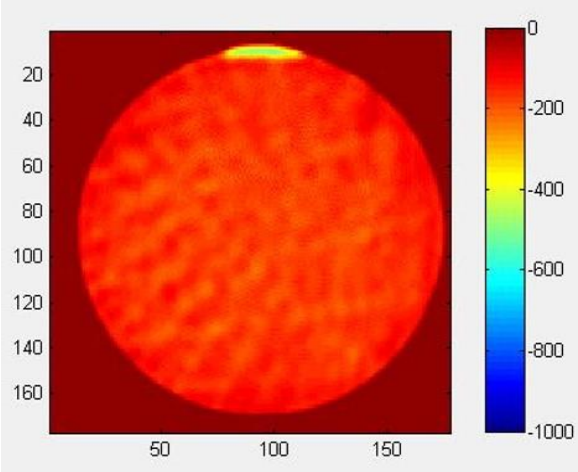
Determination of Miscibility Pressure of CO_2 in Dead Bakken Crude @ 38 ºC (~100 ºF)



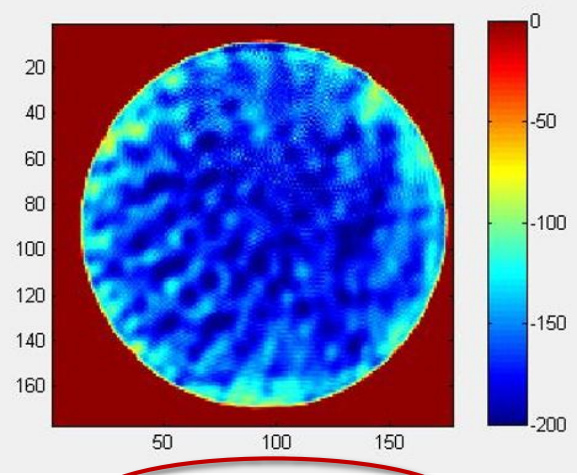
Oil @ ambient P



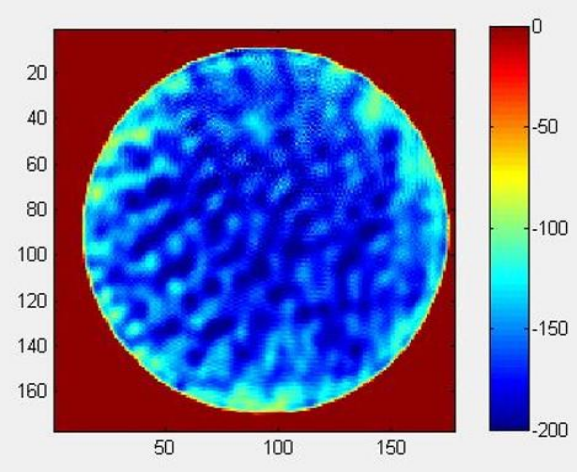
Oil/CO_2 @ 1000 psi



Oil/CO_2 @ 1100 psi



Oil/CO_2 @ 1200 psi

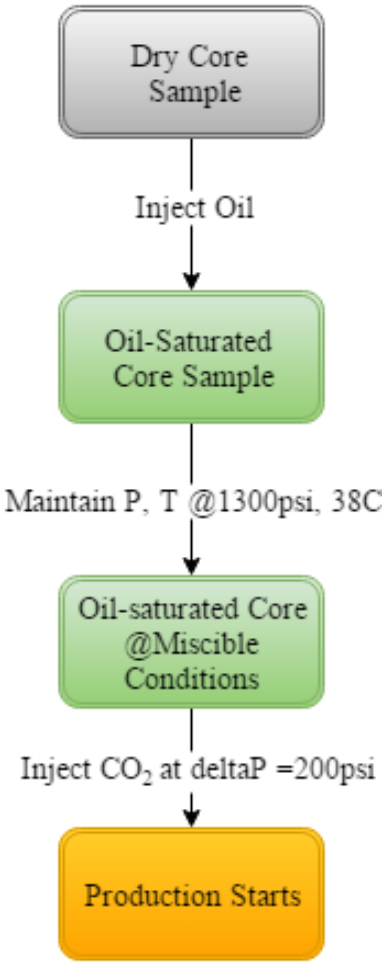


Oil/CO_2 @ 1300 psi

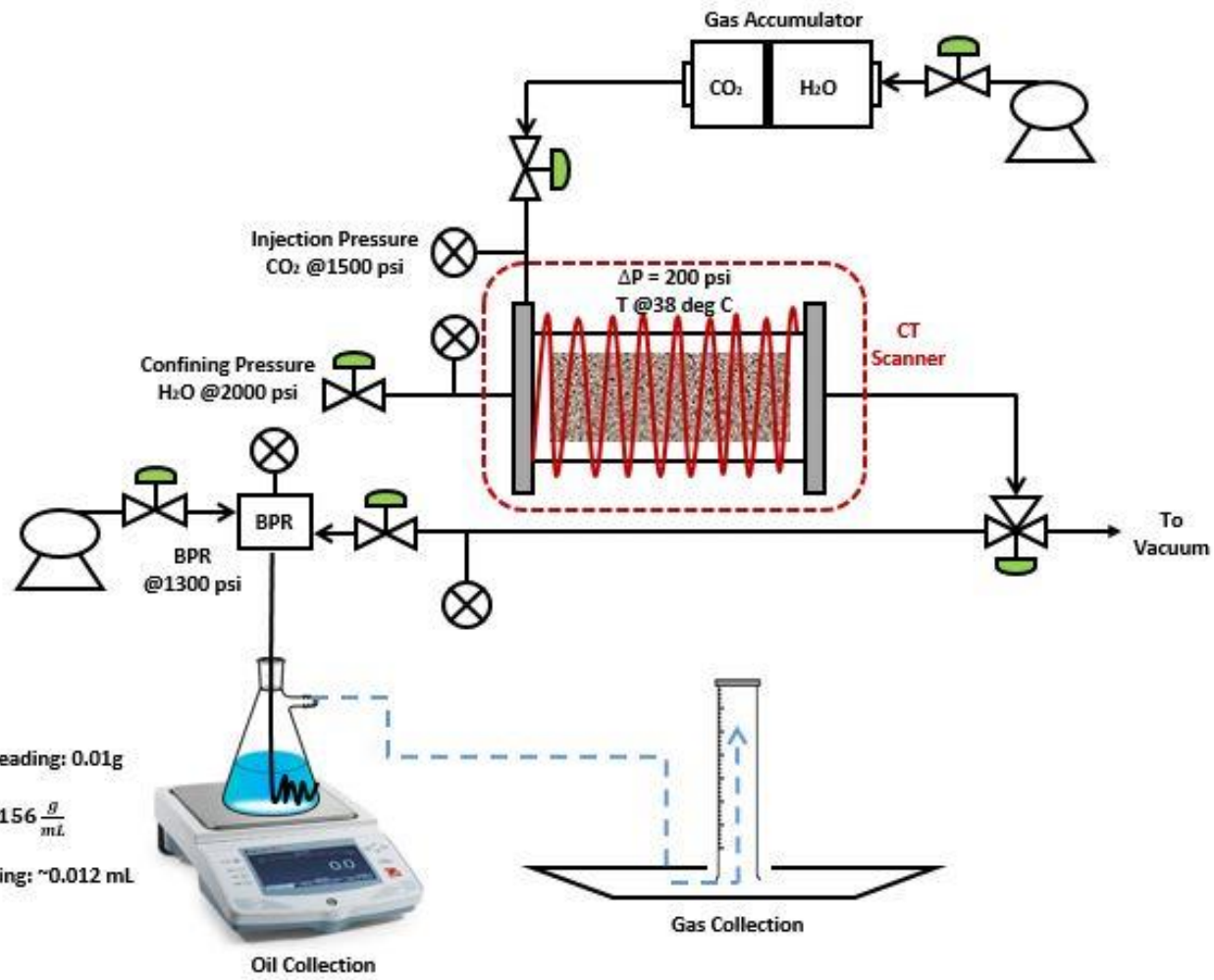
Typical Bakken Reservoir Condition:

- 150 to 240 ºF
- > 4,000 psi

Experimental Plan

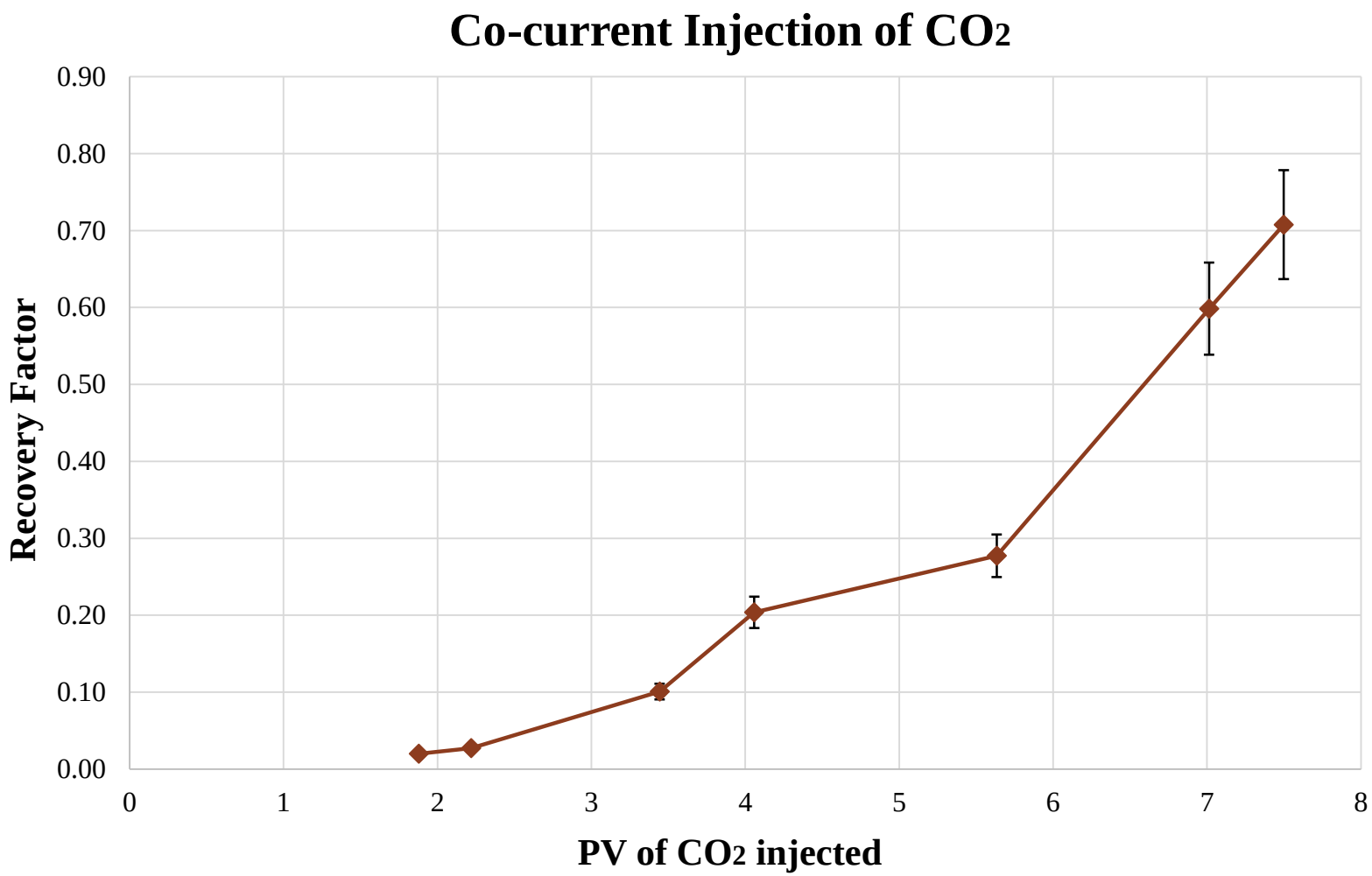


Experimental Set-up



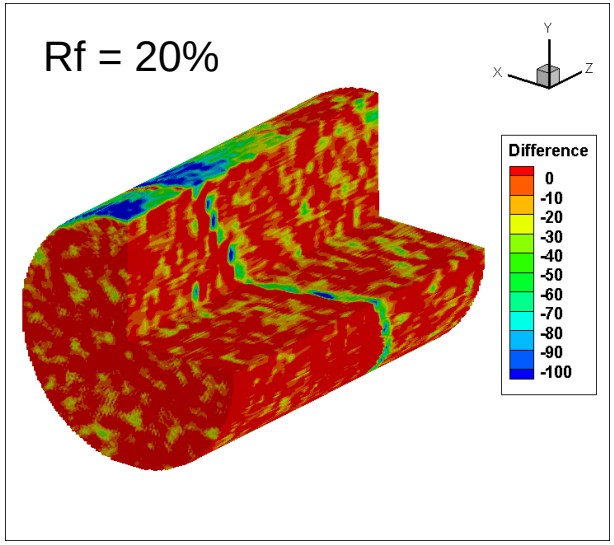
- Min mass reading: 0.01g
- $\rho_{oil} = 0.8156 \frac{g}{mL}$
- Min V reading: ~0.012 mL

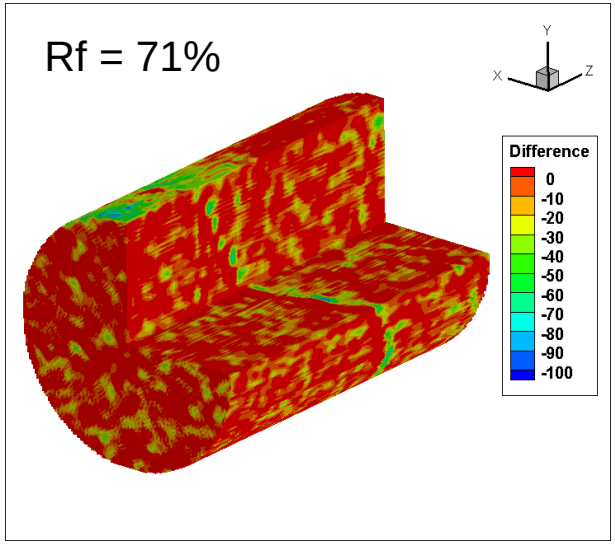
Oil Recovery: 70%+ of OOIP from Bakken Core



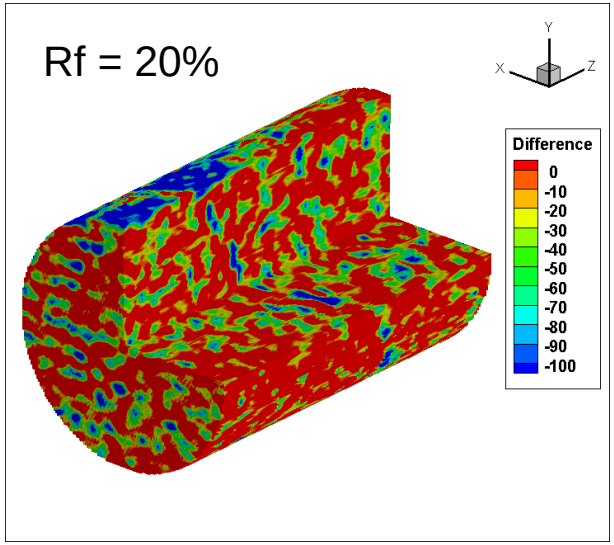
Subtraction of Oil Images from CO_2 Images at High and Low Energy Levels

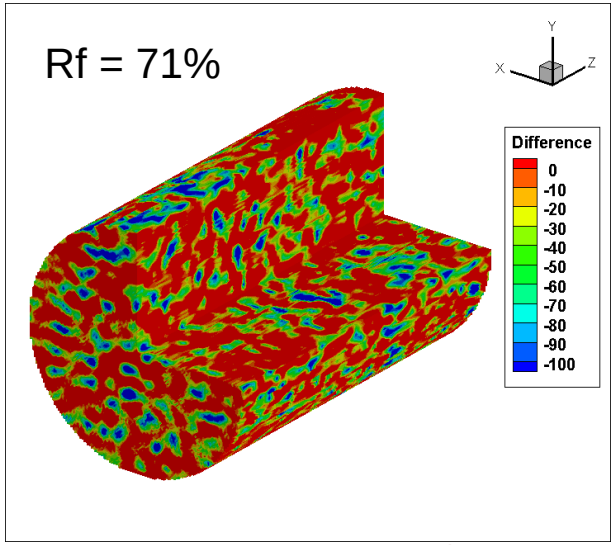
140 keV





80 keV





Compositional Analysis of the Bakken Crude

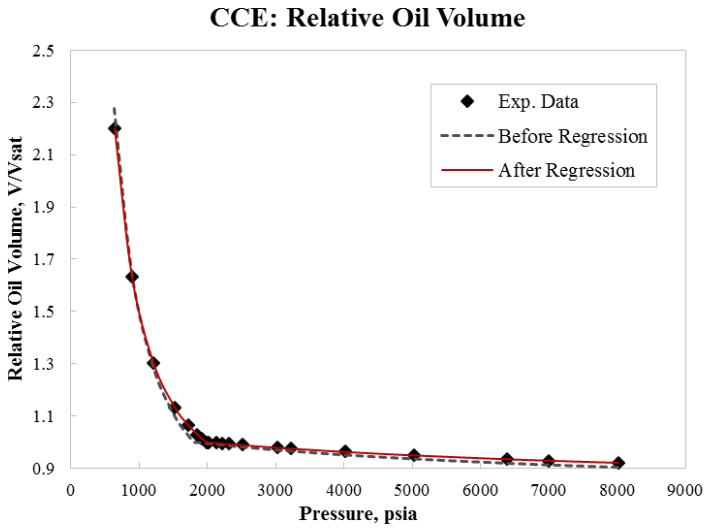
- Model specifications:
  - Peng-Robinson EOS with volume correction
  - Aromatics and cycloalkanes lumped into C_{7+}
  - Expand from C_7 to C_{200} and lump into 5 pseudo-components
  - Limited use of non-zero binary interaction coefficients

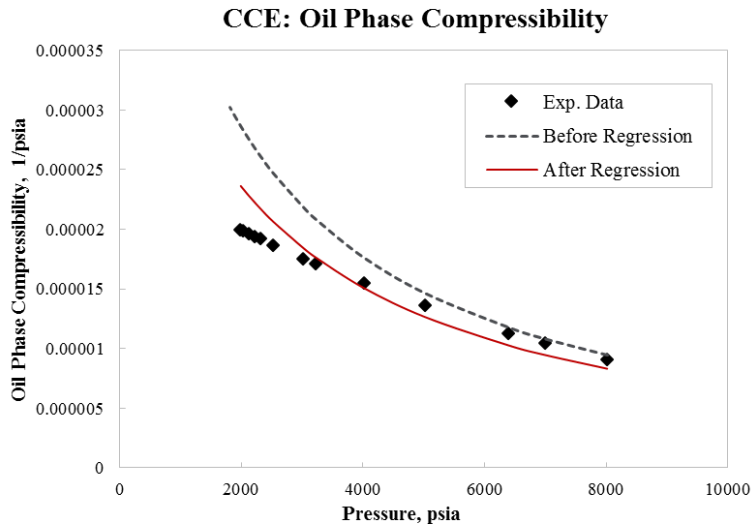
- Regression study with PVT experimental data
  - Constant Composition
  - Differential Liberation

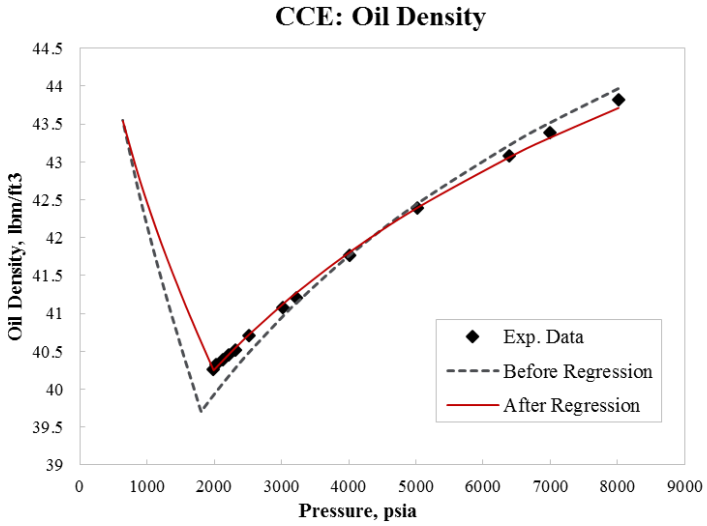
Comparison of Saturation Pressure at T= 237 ºF

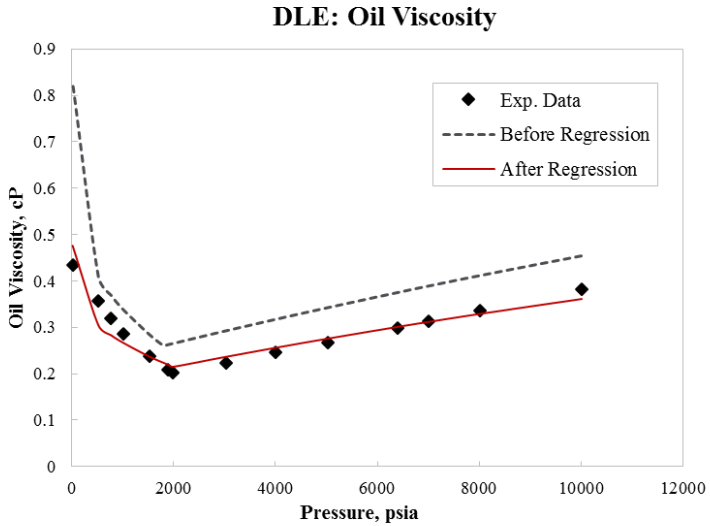
	Model Prediction	Experimental Data	%Error
Saturation Pressure	1991.51 psia	1986 psia	0.3

Comparison of CCE and DLE Data at T= 237 ºF









Dead Oil Composition from Two-Phase Flash

Component	Molar Composition of Live Oil	Molar Composition of Flashed Liquids
CO2	0.00260	0.00007
N2-CH4	0.25056	0.00196
C2H6	0.11868	0.00846
C3H8	0.09758	0.02461
IC4 - NC4	0.06399	0.04314
IC5 - NC5	0.04029	0.05275
C6	0.03379	0.05922
C7 - C10	0.18346	0.37769
C11 - C13	0.07872	0.16270
C14 - C17	0.06091	0.12592
C18 - C21	0.03244	0.06706
C22+	0.03696	0.07641

MCM Pressure of Dead Oil at 38 ºC

- Method of Characteristics (Orr): 1069.5 psi
- Method of Multiple Mixing Cells (Ahmadi & Johns): 1175.49 psi
- Experimental Miscibility: 1200 psi

	Method of Characteristics	**Method of Multiple Mixing Cells**
% Error	12%	2%

Conclusion

- CO_2 proves to be a promising EOR agent for light crudes in Bakken
  - Production starts after more than 1PV of CO_2 injected
  - At least 70% of OOIP recovered
- Impact of CO_2 injection is more pronounced at low-energy-level CT scans due to contribution of photoelectric absorption
- Existence of fractures aids the transport of CO_2
- Fluid model is capable of producing reasonable representation of PVT test results

Future Work

- More coreflood experiments to obtain good volumetric data on the effect of CO_2 on oil recovery

- For imaging purpose,
  - Longer exposure time
  - Use photoelectric dopants

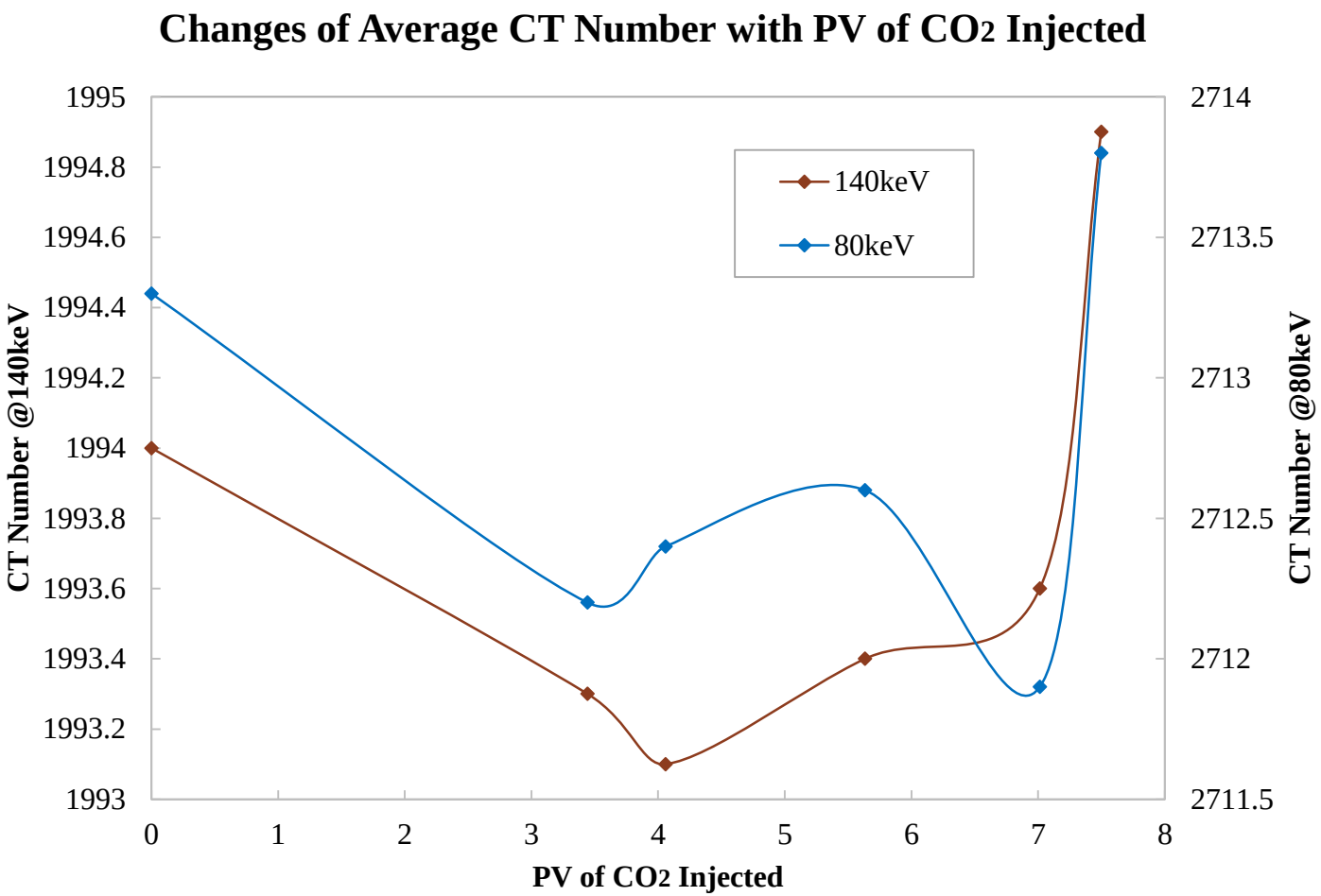
- Flow simulation in CMG GEM to reproduce the miscible experiments

Acknowledgement

- SUPRI-A Team
- Industry Affiliates

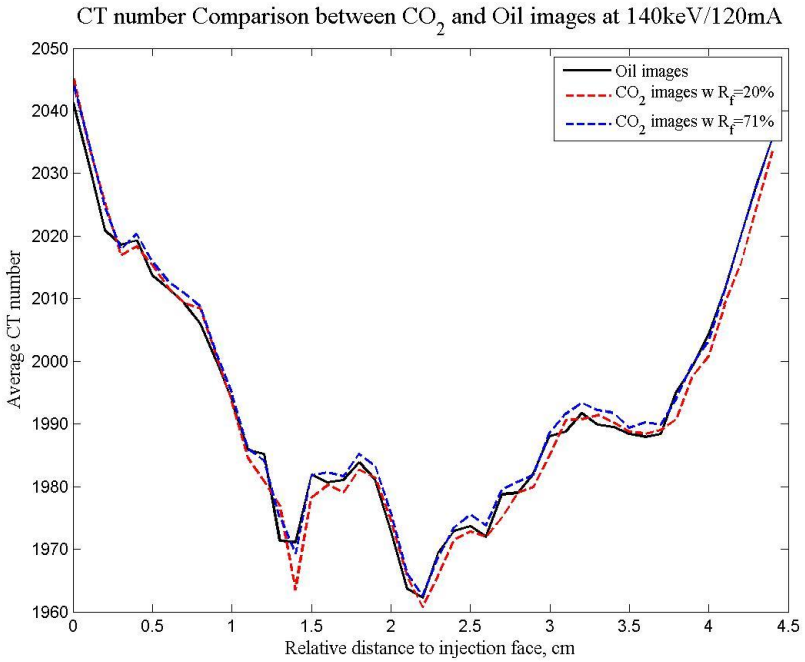
Appendix

CT Number Comparison with PVI of CO_2

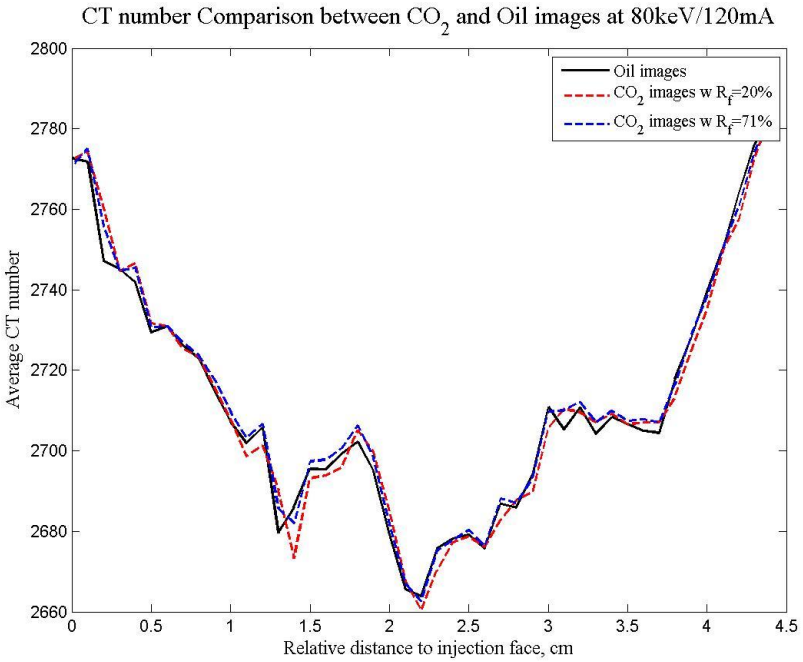


CT Number Comparison at High and Low Energy Levels

High Energy Level



Low Energy Level



Theoretical Reconstruction of CT Number Difference at Energy Level of 140 keV

$$CT = (1-\phi)\cdot CT_{rock} + \phi \cdot CT_{fluid}$$

$$\Delta CT = \phi \cdot (CT_{fluid}(t) - CT_{fluid}(t=0))$$

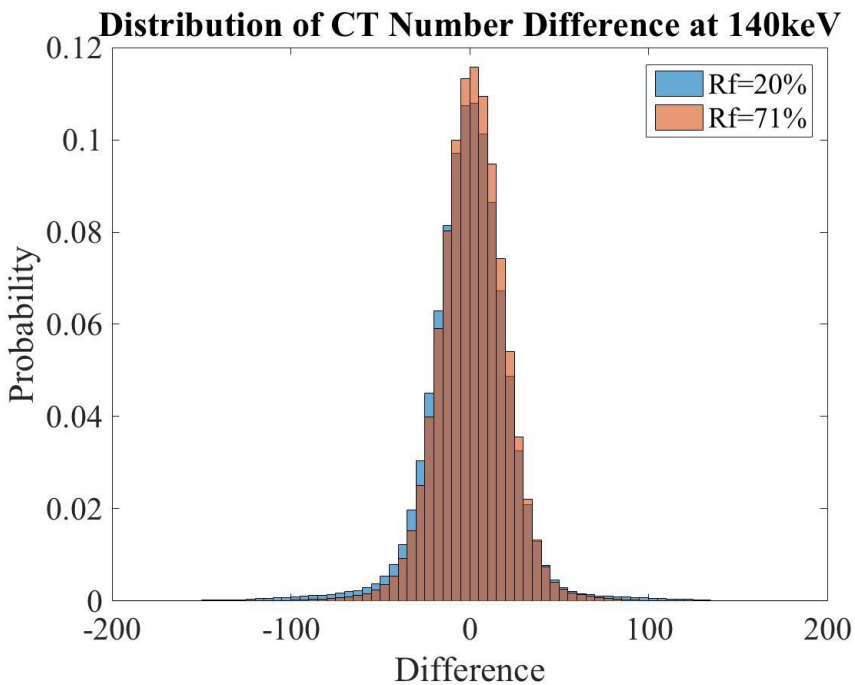
$$CT_{fluid}(t) = x_{CO2} CT_{CO2} + (1 - x_{CO2}) CT_{oil}$$

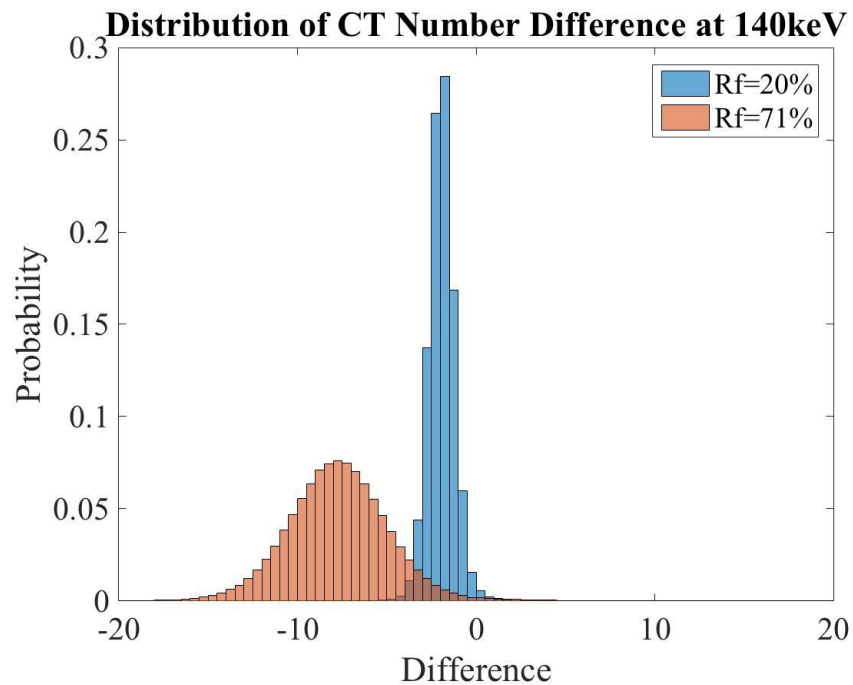
$$CT_{fluid}(t=0) = CT_{oil}$$

$$x_{CO2} = \frac{R_f \rho_{CO2}}{(1-R_f)\rho_{oil} + R_f \rho_{CO2}}$$

	Density g/mL	**Pure Fluid CT Number @140keV**
CO_2	0.616	-335.1
Oil	0.785	-177.4

Histogram of CT Number Differences: Experimental vs. Theoretical





CT Number Comparison @ ϕ=7.5%: Theoretical vs. Experimental