Energy & Environmental Research Center (EERC)

OVERVIEW OF TWO EERC BAKKEN CO_2 EOR PROJECTS CONDUCTED FROM 2011 TO 2018

IMPROVED CHARACTERIZATION AND MODELING OF TIGHT OIL FORMATIONS FOR CO_2 ENHANCED OIL RECOVERY POTENTIAL AND STORAGE CAPACITY ESTIMATION
AND
BAKKEN CO_2 STORAGE AND ENHANCED RECOVERY PROGRAM

Presented to North Dakota Industrial Commission Oil & Gas Research Council

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Critical Challenges. **Practical Solutions.**

BAKKEN CO_2 STORAGE AND ENHANCED RECOVERY PROGRAM – PHASES I AND II (A.K.A. "BAKKEN CO_2 EOR") PARTNERS

North Dakota
oil & gas research program

Marathon Oil

Continental
RESOURCES

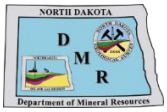
XTO
ENERGY

HESS

BAKER
HUGHES

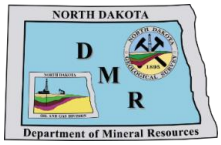
CMG
COMPUTER
MODELLING
GROUP LTD.

Schlumberger



NORTH DAKOTA
PETROLEUM
COUNCIL

IMPROVED CHARACTERIZATION AND MODELING OF TIGHT OIL FORMATIONS FOR CO_2 ENHANCED OIL RECOVERY POTENTIAL AND STORAGE CAPACITY ESTIMATION (A.K.A. "TIGHT OIL CHARACTERIZATION AND MODELING") PARTNERS



A TALE OF TWO PROJECTS

- Two separate but complementary research projects.
- Key similarities:
  - Substantial funding from DOE and NDIC OGRP.
  - **Ultimate goal to support efforts to improve oil recovery from the Bakken.**
  - Laboratory efforts to evaluate ability of CO_2 to mobilize Bakken oil.
  - Modeling efforts to improve our understanding of the mechanisms controlling CO_2 EOR in the Bakken and evaluate potential CO_2 EOR schemes.
- Key differences:
  - One emphasized detailed, advanced characterization of pore throat networks.
  - One emphasized a CO_2 injection test in a vertical Bakken well.

"Bakken CO_2 EOR – Phase I" (2011–2014)

Partner	Cash	In Kind
DOE	$675,000	NA
NDIC OGRP	$475,000	NA
Marathon	$50,000	$163,000
Continental Resources	$50,000	NA
TOTAL	**$1,250,000**	**$163,000**

Total Phase I Value = **$1,413,000**

"Bakken CO_2 EOR – Phase II" (2014–2018)

Partner	Cash	In Kind
DOE	$2,623,558	NA
Hess	$250,000	NA
XTO Energy	$150,000	$450,057
CMG	NA	$467,000
Schlumberger	NA	$337,094
Baker Hughes	NA	$994,407
TOTAL	**$3,023,558**	**$2,248,558**

Total Phase II Value = **$5,272,116**

"Tight Oil Characterization" (2014–2017)

Partner	Cash
DOE	$2,500,000
NDIC OGRP	$400,000
NDIC LEC	$250,000
TOTAL	**$3,150,000**

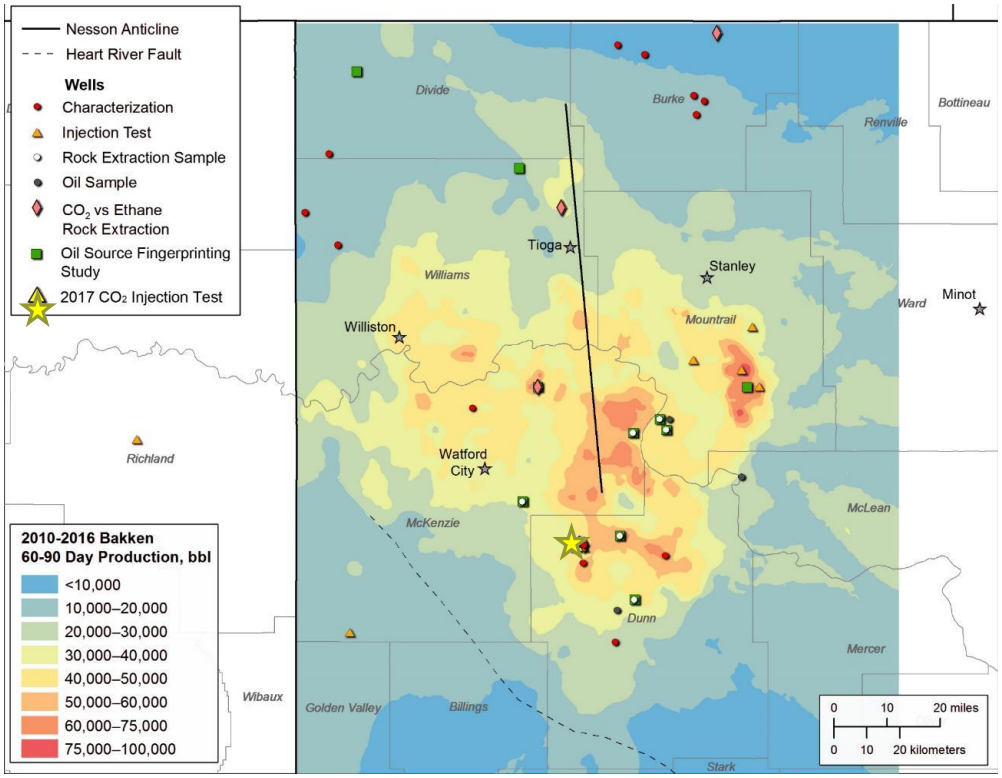
Total Tight Oil Value = **$3,150,000**

EERC Bakken CO_2 EOR Efforts

Since 2011, NDIC OGRP contributions of *$875,000* have been leveraged to create a total program value of *$9,835,116*.

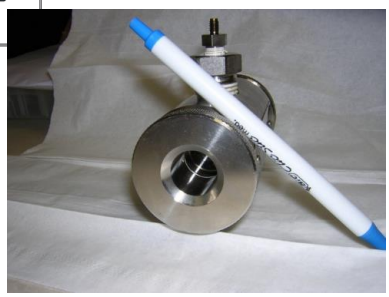
STUDY LOCATIONS

- EERC studies have used rock and/or fluid samples from locations throughout the Bakken play in North Dakota.
- The field test with XTO Energy was conducted in Dunn County.
- Marathon samples came from Dunn, McKenzie, and Mountrail Counties.
- NDGS provided all other samples.



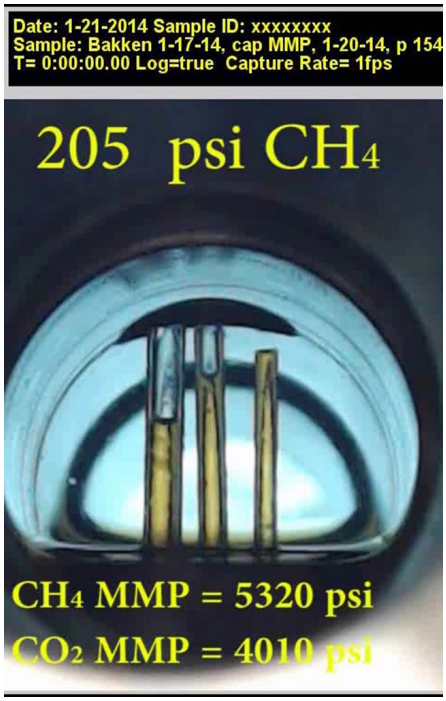
LAB AND MODELING STUDIES

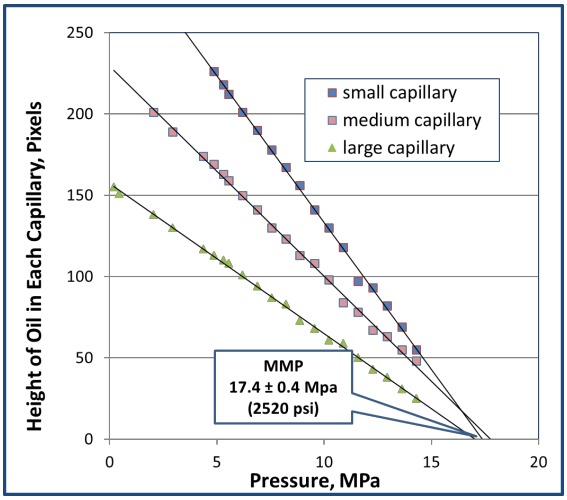
MMP BY CAPILLARY RISE-VANISHING INTERFACIAL TENSION



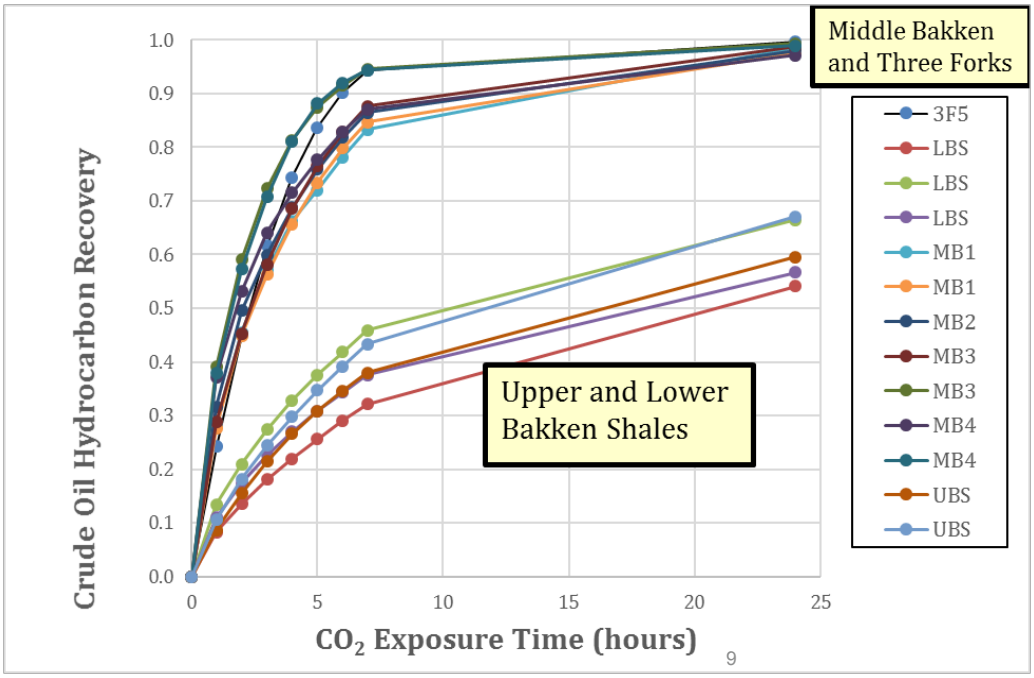
Patent pending

1.12, 0.84, 0.68 mm i.d.





Laboratory Plug-Scale CO_2 Oil Recovery from Six Bakken Lithofacies from a McKenzie County Well (24 hours)



These types of data were generated for 46 core plug samples from six different wells.

- Two wells each in Dunn, Mountrail, and McKenzie Counties.

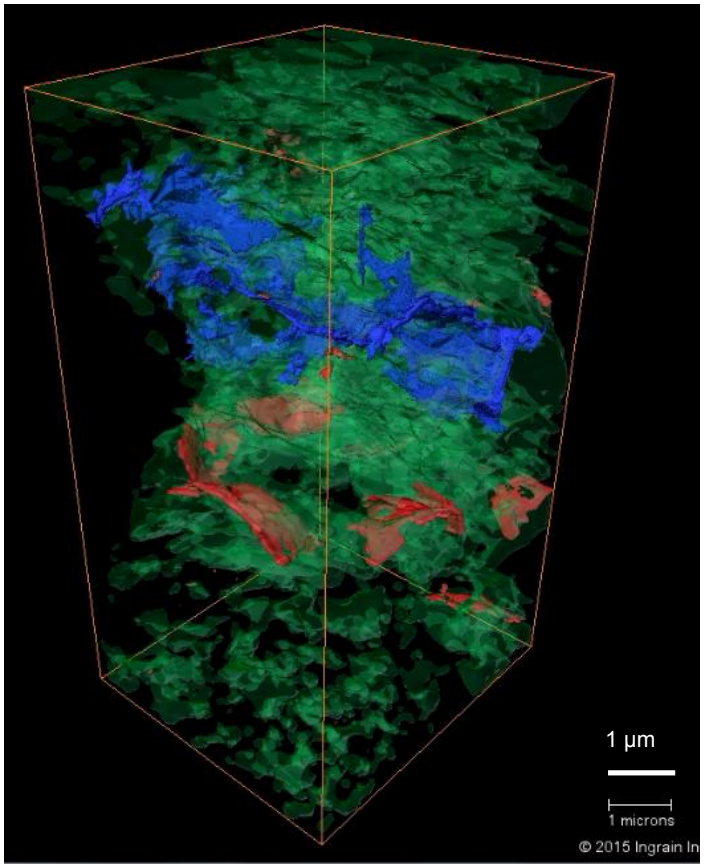
BAKKEN SHALE FIB–SEM ANALYSIS

Green = organics
Red = unconnected Φ
Blue = connected Φ

Shales are dominated by intergranular distribution of organics, likely kerogen.

The amount of connected and unconnected pore space is roughly equal.

The organics absorb CO_2 and may also be a pathway for CO_2 diffusion, thereby facilitating oil mobilization from the shale.



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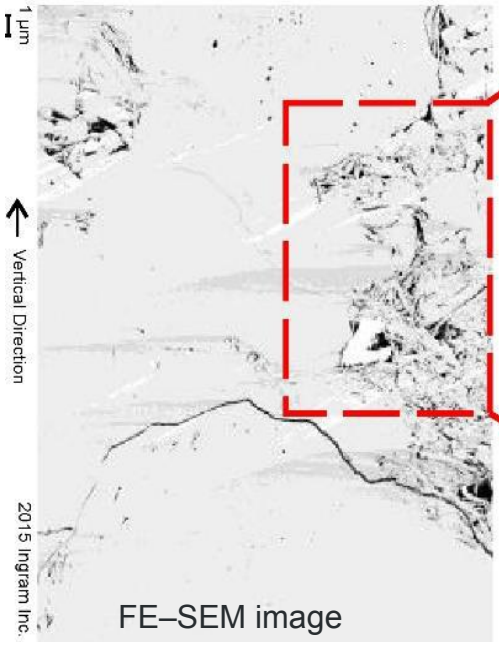
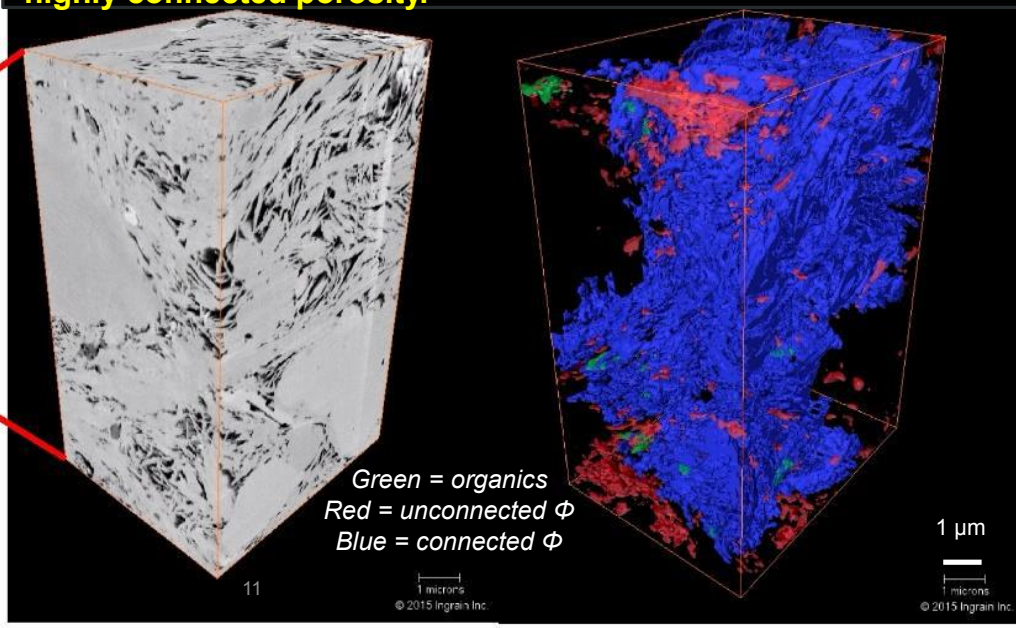
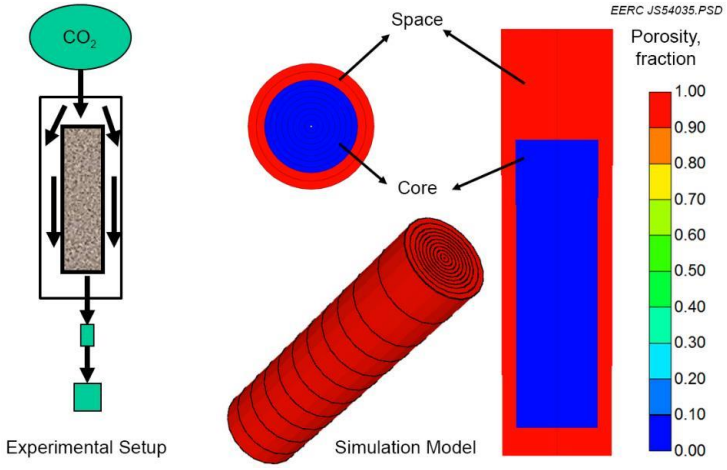
FESEM AND FIB–SEM OF MIDDLE BAKKEN MICROFRACTURES



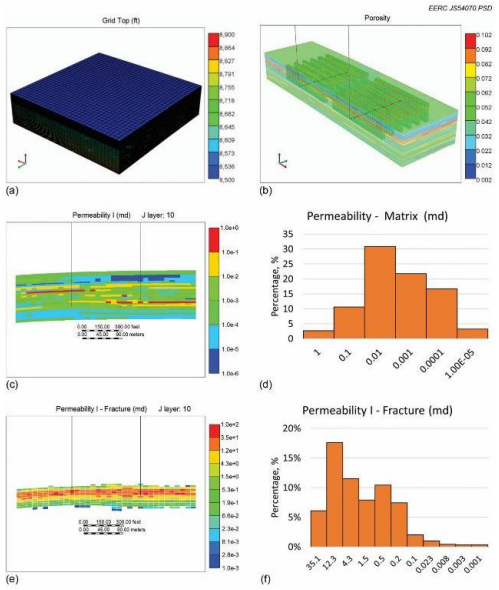
FIB-SEM Image: Clay-filled microfractures appear to have highly connected porosity.



MODELING AND SIMULATION ACTIVITIES



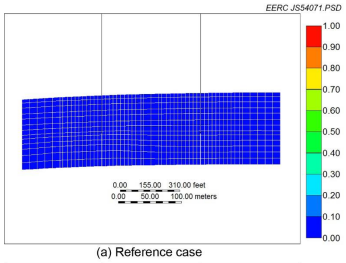
Core Scale to Evaluate Extraction Experiments



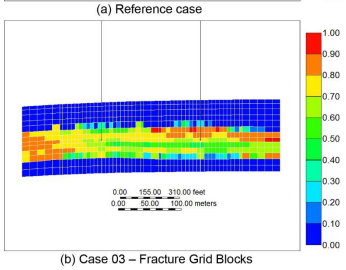
Reservoir Scale to Estimate CO_2 EOR and Storage in the Bakken

RESERVOIR SCALE HUFF ‘N’ PUFF MODELING RESULTS

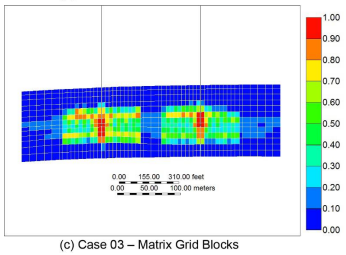
- Best results were from a case with nine huff ‘n’ puff cycles over 10 years, total production over 30 years.
- **Results show incremental oil recovery ranges from 0.6% to 5.4% improvement in recovery factor.**
  - **(i.e., recovery factor went from 17% to 23.4%).**
- Modeling suggests conservative estimate of *net* CO_2 utilization is 1.8 mscf/bbl.



(a) Reference case

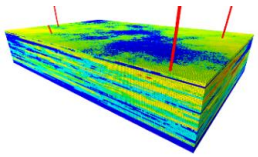


(b) Case 03 – Fracture Grid Blocks



(c) Case 03 – Matrix Grid Blocks

FIELD CO_2 INJECTION TEST



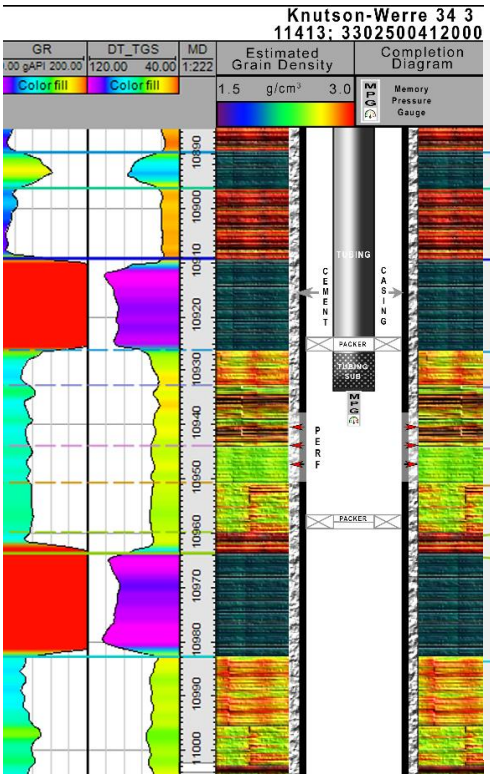
TEST CONCEPT AND HYPOTHESIS

Past pilot-scale CO_2 injection tests into horizontal, hydraulically fractured Bakken wells have shown little to no effect on oil mobilization.

- CO_2 likely moved so quickly through fractures that it did not have enough contact time, or became too dispersed, to interact with stranded oil in the matrix.

Hypotheses to Be Tested in a Vertical Well

1. CO_2 can be injected into an unstimulated Bakken reservoir.
2. The injected CO_2 can interact with the in-place fluids, resulting in subsequent mobilization of hydrocarbons and storage of CO_2.

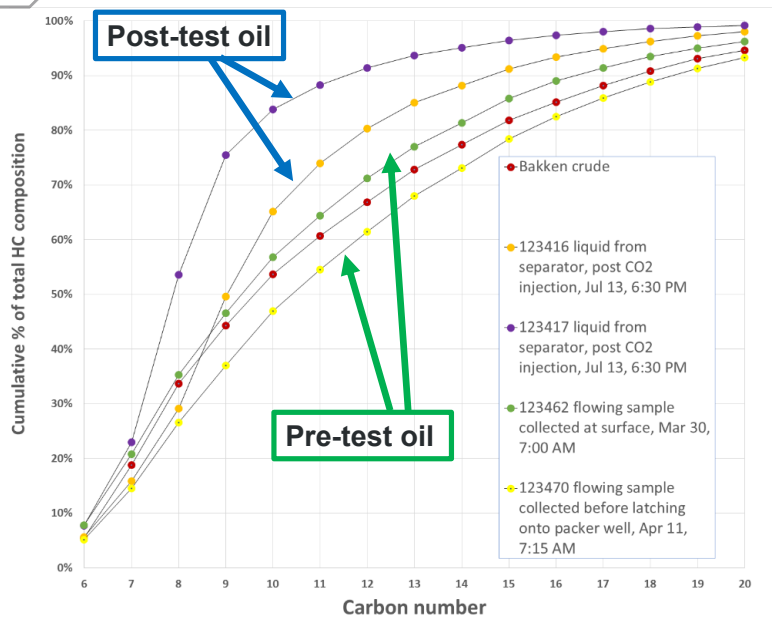


INJECTION TEST STATISTICS

- Initial BHP ~7500 psi
- Stable injection rates between 6 and 12 gpm
- Maximum BHP ~9480 psi
- BHP during continuous injection ~9400 to ~9470 psi
- Temperature range 251° to 257°F

Day	Date	Total Cum [gal]	Cum Mass [tons]	Period
1	24-Jun	2236.7	10.4	Filling
1	24-Jun	50.8	0.2	BHP from 8200 to 8600
1	24-Jun	207	1.0	Cyclic inj- Part 1
2	25-Jun	1160.5	5.4	Cyclic inj- Part 1
2	25-Jun	904.5	4.2	Cyclic inj- Part 2
2	26-Jun	1009.4	4.7	Cyclic inj- Part 2
3	26-Jun	1752.6	8.1	Cont. Inj
4	27-Jun	11131	51.8	Cont. Inj
5	28-Jun	2806.2	13.0	Cont. Inj
		TOTAL	98.9 tons of CO_2 injected	

PRE- AND POSTINJECTION OIL COMPOSITIONAL ANALYSIS CONDUCTED BY THE EERC



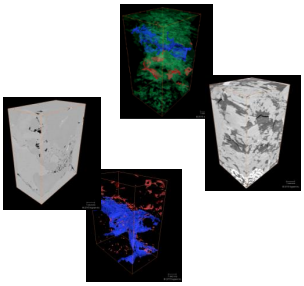
- Lab work showed CO_2 preferentially mobilizes lighter-end hydrocarbons from the matrix.
- Analysis of pre- and posttest oil samples shows there was an observable shift toward the lower-molecular-weight hydrocarbons as a result of the CO_2 injection.
- These data suggest that the CO_2 penetrated the matrix of the Middle Bakken, interacted with the oil therein, and mobilized a lighter oil.

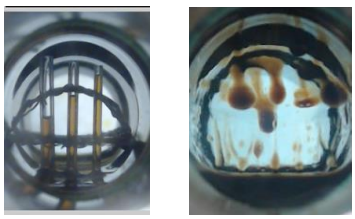
ACCOMPLISHMENTS – CO_2 FIELD TEST

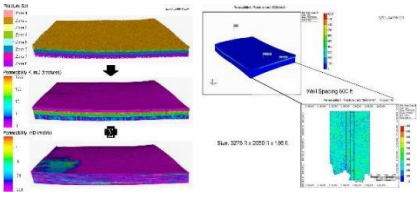
- Collaborated with XTO Energy to design and implement a CO_2 injection test.
- Injected nearly 100 tons of CO_2 into a vertical Middle Bakken well.
- Generated a wealth of real-world data:
  - Reservoir pressure and temperature
  - Fluid composition
  - Injectivity
  - Flowback
  - Evidence that CO_2 mobilized oil in matrix

ACCOMPLISHMENTS – LAB AND MODEL

- Lab work demonstrated the ability of CO_2 to permeate Bakken shales and nonshale rocks and mobilize oil.
- Refined a capillary rise-vanishing interfacial tension technique for studying phase behavior and estimating minimum miscibility pressure (MMP).
- Generated insight on the key characteristics and mechanisms controlling CO_2 permeation and oil mobility.
  - Concentration gradient-driven diffusion
  - Sorption
- Cyclic huff ‘n’ puff may yield 0.6% to 5.4% improvement in recovery factor.







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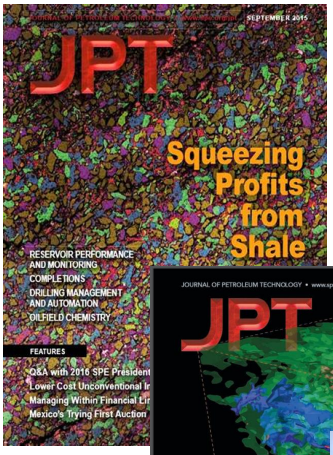

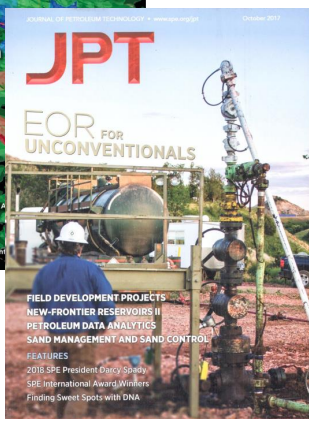

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