EXPERIMENTAL DATA SUPPORTING CO_2 ENHANCED OIL RECOVERY AND STORAGE POTENTIAL IN THE BAKKEN PETROLEUM SYSTEM (BPS)

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EXECUTIVE SUMMARY

- Improved oil recoveries using CO_2 are possible from the Middle Bakken (MB) and Upper Three Forks (TF) target drilling zones and the Upper and Lower Shales (UBS, LBS), but recoveries will be best with highly accessible rock surface area, long exposure times, and high CO_2 pressures.
- Higher pressures enhance the ability of CO_2 to dissolve crude oil hydrocarbons, swell bulk crude oil, and recover residual oil from Bakken mudrocks and shales regardless of pressures being below, at, or above minimum miscibility pressure (MMP).
- UBS and LBS rocks strongly sorb CO_2 into the rock matrix and have a large potential storage capacity, even at relatively low pressures. In contrast, CO_2 storage capacities of TF and MB zones are dominated by filling pore spaces and, therefore, depend directly on CO_2 pressure.
- Better descriptions of the accessible rock volumes are needed to estimate the CO_2 storage potentials of the BPS.

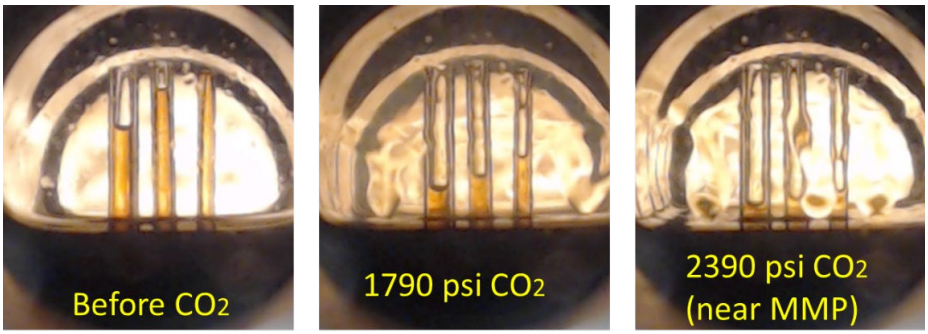
APPROACH

Tests were conducted at the system temperature of 230°F (110°C) and pressures up to 5000 psi using crude oils produced from the MB and TF Formations. CO_2 exposures to investigate residual oil recoveries and sorption isotherms were also conducted with rock cores collected from the LBS and UBS source shales and the MB and TF target drilling zones.

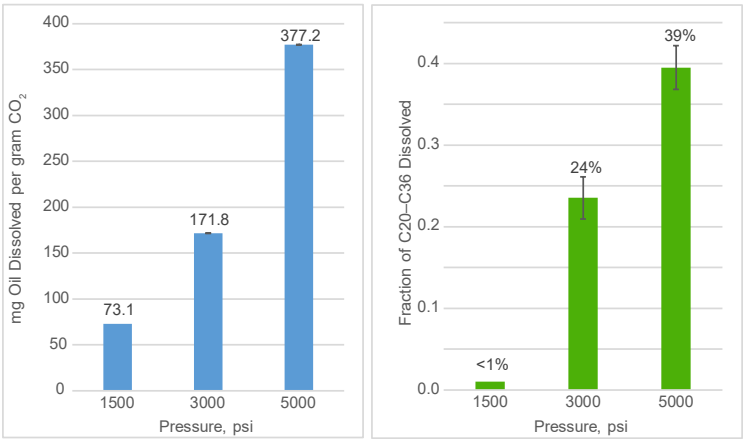
RESULTS

MMP[1]

Measured CO_2 MMPs for crude oil produced from the MB (MMP = 2540 psi) and TF (MMP = 2710 psi) are about one-half those of the original reservoir pressures.



Capillary-rise determination of Bakken crude oil MMP exposed to CO_2.



Mass of crude oil hydrocarbons dissolved (mg oil/g CO_2 [left]) and the fraction of the heavy hydrocarbons (C20–C36) dissolved as CO_2 pressures rise from 1500 to 5000 psi (right).

Ability to Dissolve Bakken Crude Oil Light and Heavy Hydrocarbons[2]

- Total crude oil hydrocarbons dissolved by exposure to CO_2 increase dramatically with pressure, whether below or above MMP.
- Lighter hydrocarbons dissolve most efficiently, causing an increase in the remaining oil's viscosity after CO_2 exposure, especially at lower pressures.
- CO_2's ability to dissolve heavier hydrocarbons (C20–C36) increases dramatically at higher pressures but is still not completely efficient.

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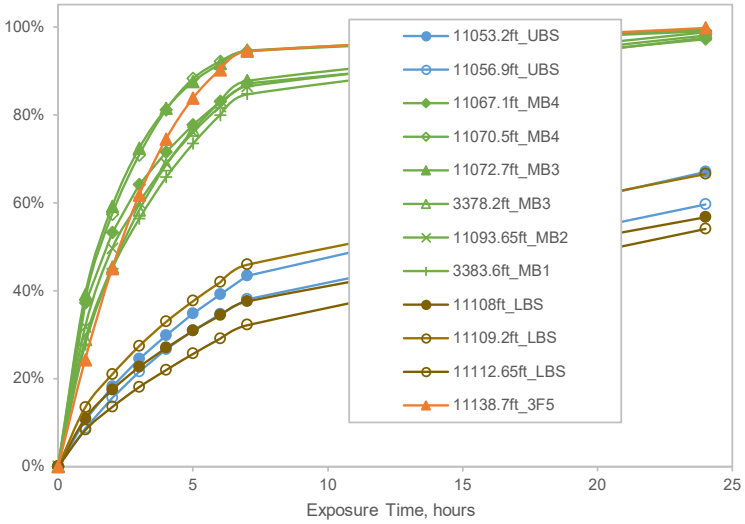
Crude Oil Volumetric Swelling[3]

- CO_2 effectively swells crude oil, which should help force oil out of rock nanopores.
- At MMP (2540 psi), Bakken crude oil swells by a factor of 1.3. Swelling continues to increase to 1.5 times the original oil volume at 5000 psi.

Bakken crude oil swelling upon exposure to CO_2 at reservoir temperature (230°F).

Residual Oil Recovery from MB, TF, and LBS/UBS Cores Collected from Nine Wells Across the Basin[4,5]

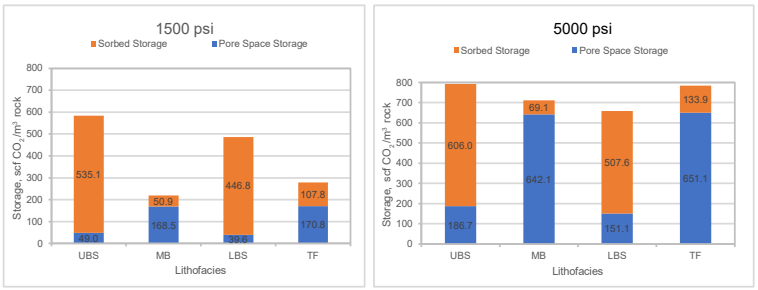
- Higher CO_2 pressures yield better hydrocarbon recoveries from 11.2-mm-diameter rock cores from all formations regardless of MMP.
- Residual oil recoveries with 5000 psi CO_2 (24 hours) exceed 90% for MB and TF cores and range from 10% to 70% for UBS/LBS cores.
- Higher accessible rock surface area, longer exposure times, and higher CO_2 pressures increase oil recoveries.



Typical residual oil recoveries with CO_2 at 5000 psi from 11.2-mm-diameter rock cores from NDIC Well 24123.

Sorption Isotherms with 25 Rock Cores from the TF, LBS, MB, and UBS[6]

- CO_2 storage in TF and MB Formations is dominated by pore space filling, so storage potential is directly related to CO_2 pressure and accessible pore volumes.
- CO_2 storage in LBS and UBS is dominated by sorption into the rock matrix and is nearly as high at lower pressures (e.g., 1500 psi) as at the original 5000-psi formation pressure.
- LBS and UBS can potentially store 6–10 times more CO_2 (per accessible rock volume) than the TF and MB zones.
- The volumes of MB, TF, LBS, and UBS rocks that are accessible to injected CO_2 need to be better understood to reliably estimate the CO_2 storage potential of the BPS.



Effect of CO_2 pressure on storage based on pore space filling compared to sorption to the rock matrix.

Available Published Literature

(1) Experimental Determinations of Minimum Miscibility Pressures Using Hydrocarbon Gases and CO_2 for Crude Oils from the Bakken and Cut Bank Oil Reservoirs. *Energy & Fuels* **2020,** *34* (5), 6148–6157.

(2) Comparison of CO_2 and Produced Gas Hydrocarbons to Dissolve and Mobilize Bakken Crude Oil at 10.3, 20.7, and 34.5 MPa and 110°C. *Energy & Fuels* **2020,** *34* (9), 10882–10893.

(3) Volumetric Swelling of Bakken Crude Oil with Carbon Dioxide and Hydrocarbon Gases at 110°C and Pressures of up to 34.5 Megapascals. *Energy & Fuels* **2022,** *36* (16), 9091–9100.

(4) Hydrocarbon Recovery from Williston Basin Shale and Mudrock Cores with Supercritical CO_2: Part 1. Method Validation and Recoveries from Cores Collected across the Basin. *Energy & Fuels* **2019**, *33* (8), 6857–6866.

(5) Hydrocarbon Recovery from Williston Basin Shale and Mudrock Cores with Supercritical CO_2: 2. Mechanisms That Control Oil Recovery Rates and CO_2 Permeation. *Energy & Fuels* **2019**, *33* (8), 6867–6877.

(6) Measured CO_2 Sorption Isotherms with 25 Bakken Petroleum System Rock Samples from the Lower and Upper Shales, Middle Bakken, and Three Forks Formations. *International Journal of Greenhouse Gas Control* **2023**, *127*, 103930–103941.

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