Asm Kamruzzaman, Petroleum Ph.D. Candidate, August 2022

LABORATORY ASSESSMENT OF GAS INJECTION ENHANCED OIL RECOVERY (EOR) IN LOW-PERMEABILITY SHALES

Outline

- Objective
- Background
- Materials and methodology
- Results
- Conclusions

Objectives

- Compare the oil recovery from **fluid expansion-drive vs. huff-n-puff gas injection EOR**, using hydrocarbon gas mixture, and CO_2 in low-permeability, unfractured and fractured outcrop, reservoir, and synthetic cores.
- Determine the role of **interconnected fractures** on oil recovery in unconventional reservoirs.
- Determine the impact of **gas-oil mass transfer** across fracture-matrix interface on oil recovery mechanism in stimulated unconventional shale reservoirs and assess the **role of pore type and pore-size distribution** on the efficacy of oil recovery.
- Formulate practical engineering guidelines for planning successful gas injection EOR in shale reservoirs.

Tasks and Contributions

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Tasks performed:

- Conducted 65 gas injection EOR experiments in low-permeability **synthetic cores**.
- Conducted 9 gas injection experiments in **Wolfcamp outcrop carbonate cores**.
- Conducted 2 gas injection experiments in **Wolfcamp formation siliciclastic cores**.

Expected contributions:

- Validate impact of gas-oil mass transfer across fracture-matrix interface on oil recovery mechanism in stimulated unconventional shale reservoirs.

Porous Media Rock Properties

9 x Wolfcamp carbonate cores
(2-in dia x 7-in long)

2 x Wolfcamp siliciclastic cores
(1.5-in dia x 3.1-in long)

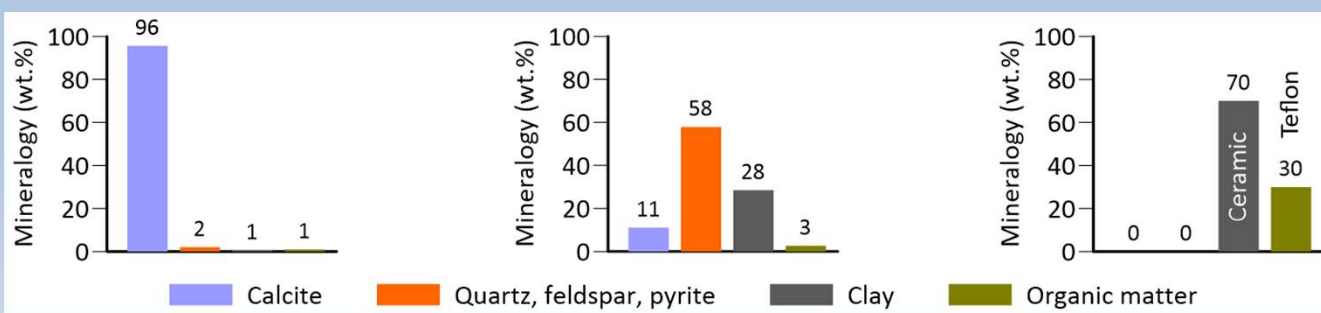
3 x synthetic cores
(2.1-in dia x 5.8-in long)

Courtesy: MUDTOC

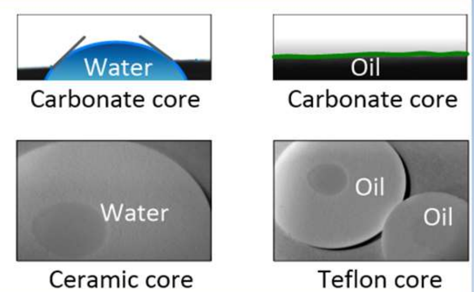
Carbonate mineralogy

Siliciclastic mineralogy

Synthetic mineralogy



Rock wettability



Porous Media Transport Properties

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9 x Wolfcamp carbonate cores
(2-in dia x 7-in long)

2 x Wolfcamp siliciclastic cores
(1.5-in dia x 3.1-in long)

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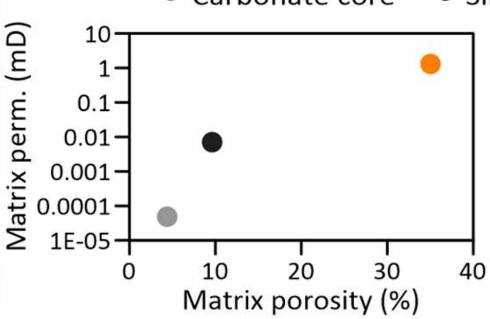
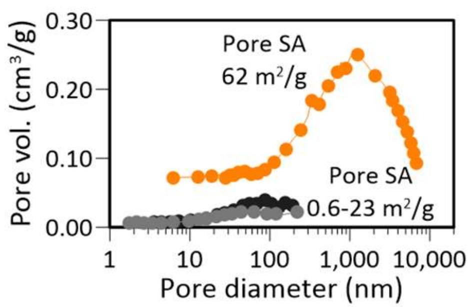
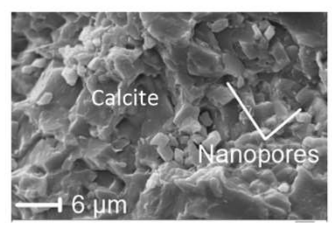
● Carbonate core ● Siliciclastic core ● Synthetic core



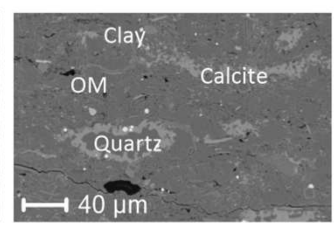


Carbonate core (SEM)



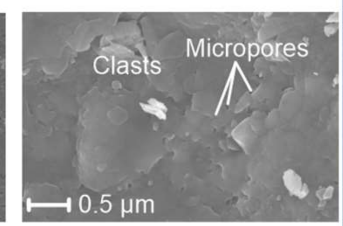
Texture:
90% grains = <4 µm

Siliciclastic core (SEM)



Texture:
50% grains = 4 - 62.5 µm

Synthetic core (SEM)



Texture:
50% grains = >62.5 µm

Gas Injection EOR in Shales—Challenges

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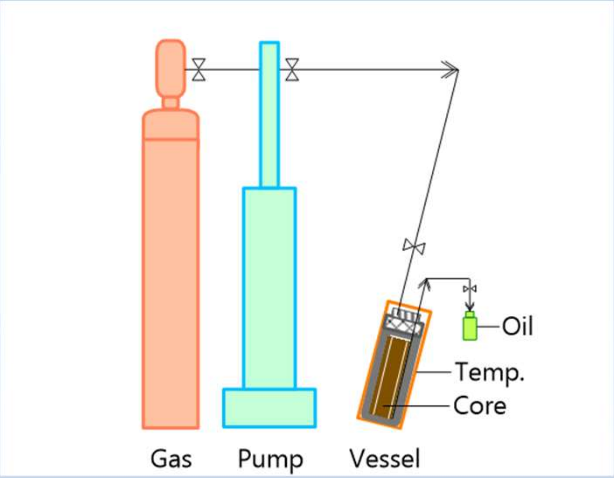
- Requires **very precise core flooding apparatus**.
- Low porosity, low permeability shale cores.
- **Very small matrix pore volume** of the shale cores.
- Too **large holdup fluid volume** at the production end of the core.

Methodology

- **Compression-decompression** system to conduct both depletion drive experiments and gas injection EOR by repressurization.
- Suitable for evaluating the **'huff-n-puff' EOR process** in shale reservoirs.

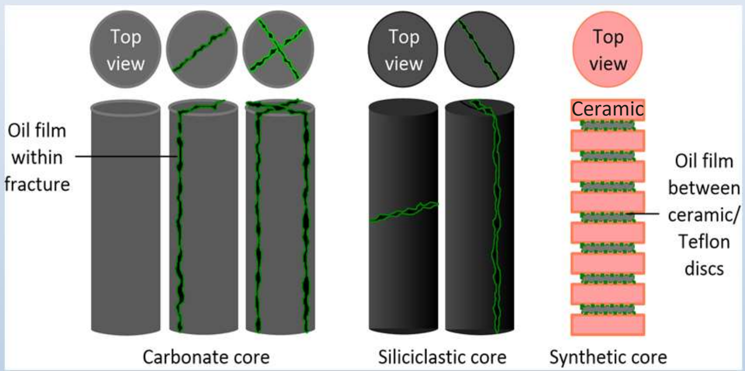
Photo of the EOR apparatus
(*Courtesy*: Lawrence Berkeley National Laboratory)

Gas injection EOR apparatus
(Simplified schematic)

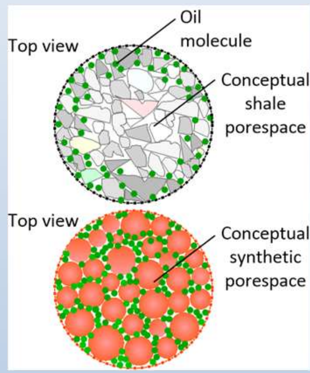


Oil Infusion Process

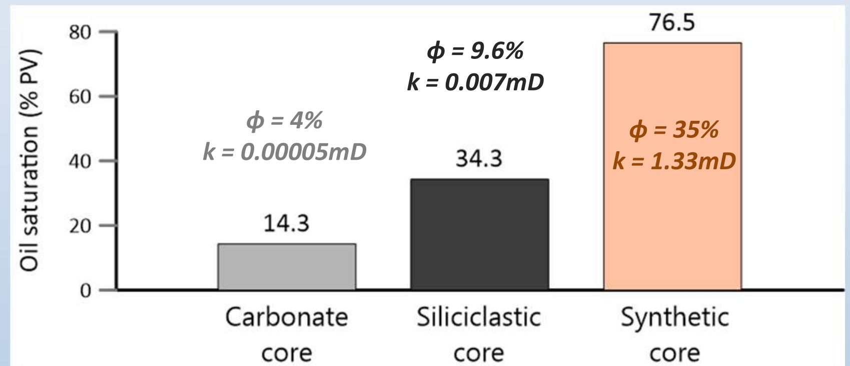
Core geometry



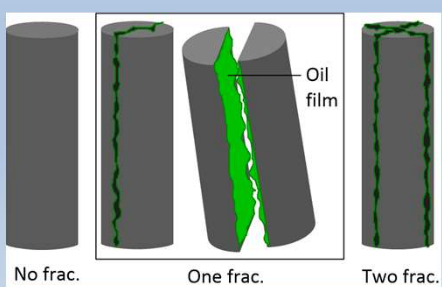
Oil infusion process



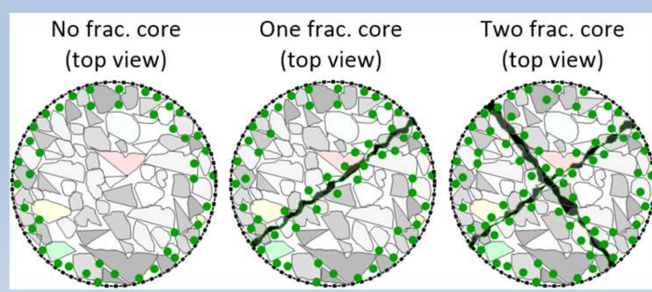
Infused oil in all cores



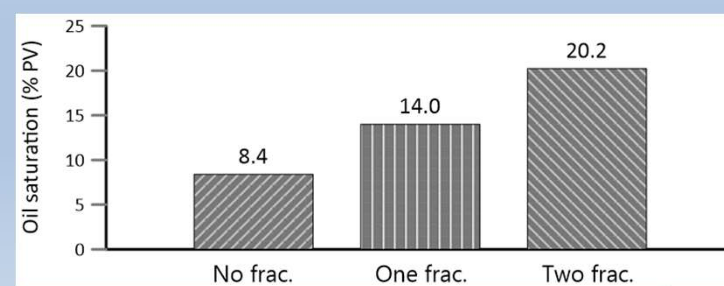
Carbonate core



Carbonate core geometry



Infused oil in carbonate cores



Primary Oil Production (Liquid Expansion)

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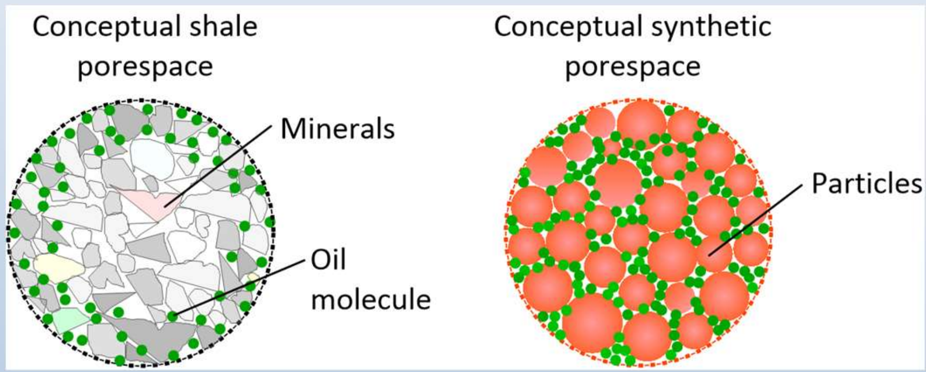
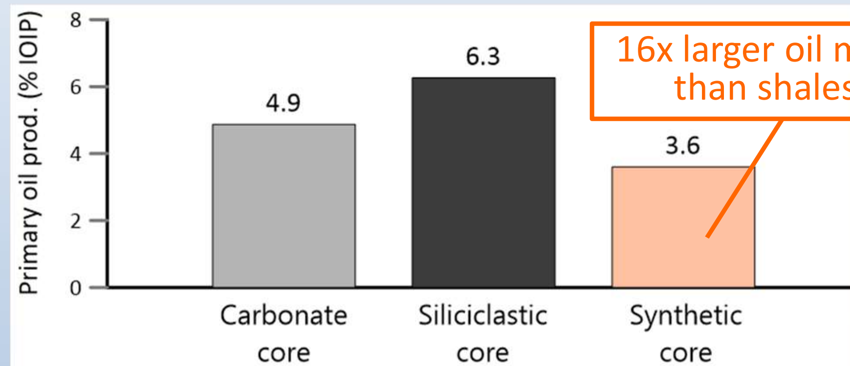
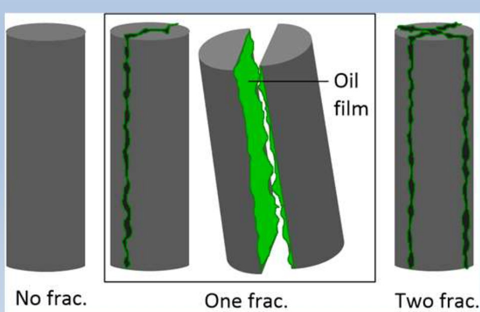
Oil infusion process



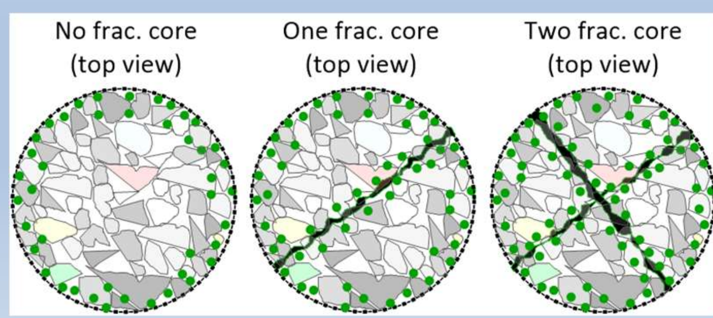
Primary oil prod. in all cores



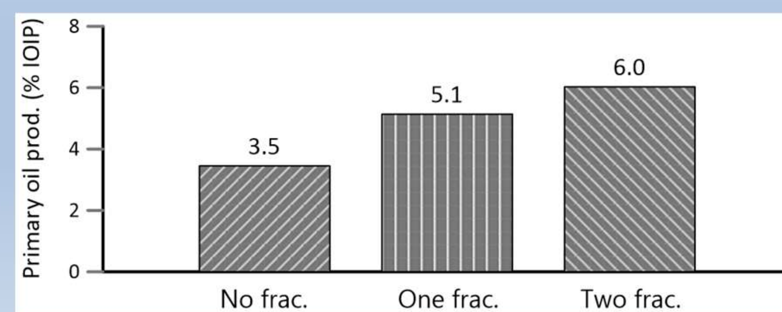
Carbonate core



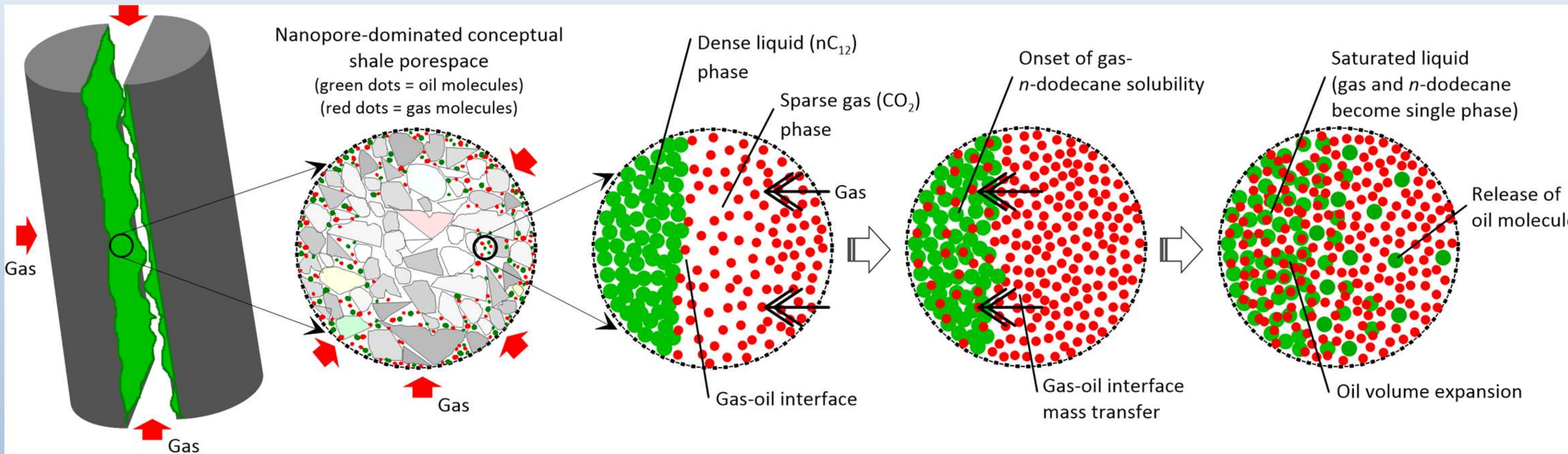
Carbonate core geometry



Primary oil prod. in carbonate cores



Gas-Oil Interface Mass Transfer



Gas in fracture interacts with matrix oil

Diffusive gas-oil mass transfer in porespace

Extraction of matrix oil via fracture surface

Phase Diagrams for nC_{12} - Gas Mixtures

Illustrating the Probable Phase Behavior of Gas-Oil Interactions

(*Courtesy*: Kaveh Amini, CSM, 2022)

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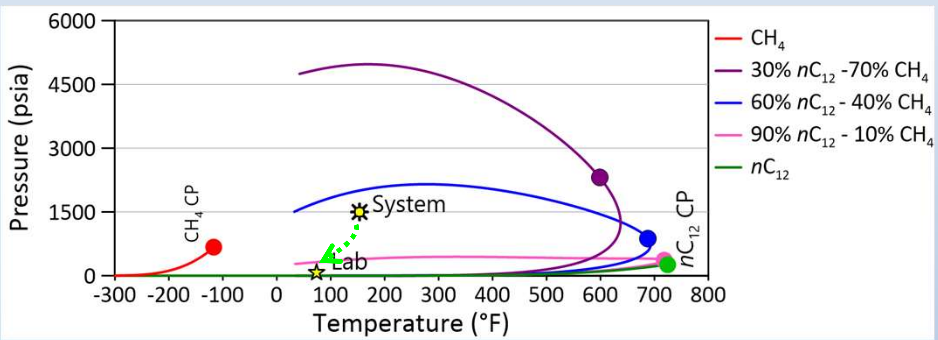
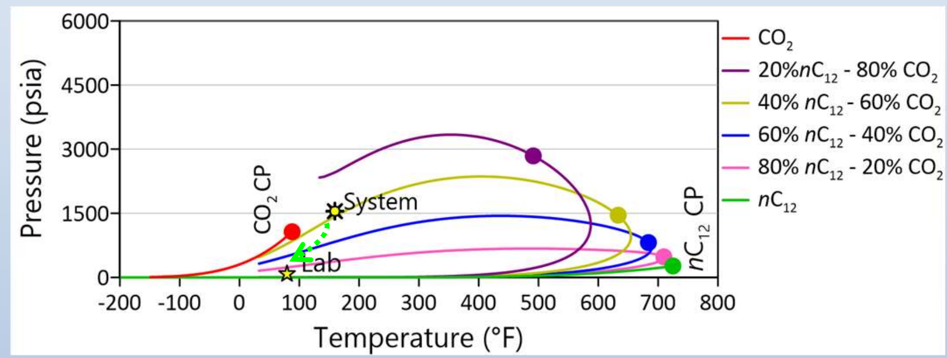
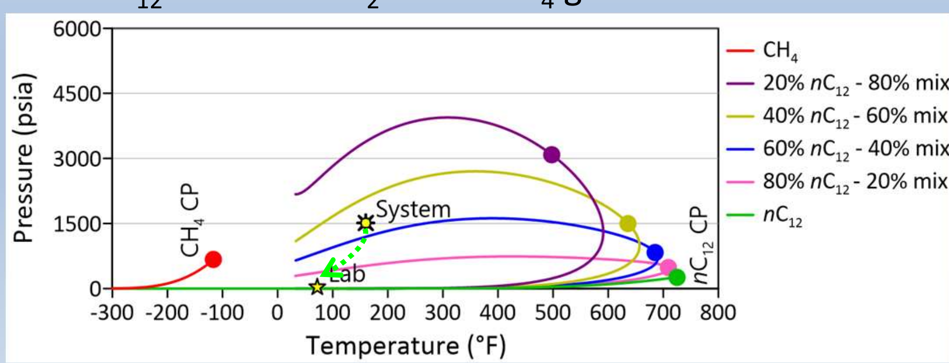
nC_{12} and CH_4 gas



nC_{12} and CO_2 gas



nC_{12} and 67% CO_2 – 33% CH_4 gas mixture



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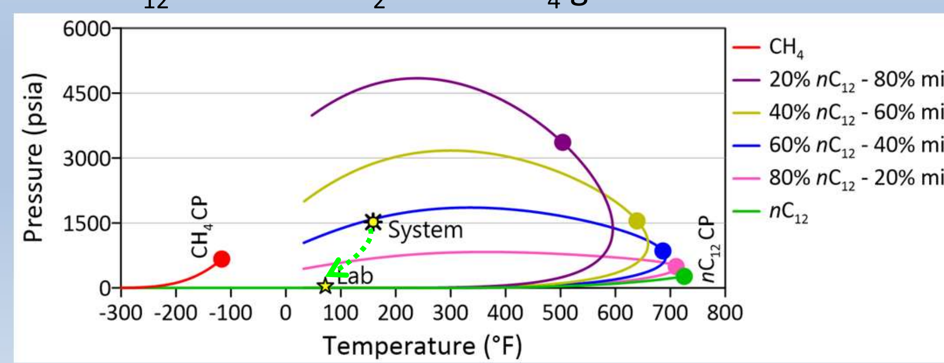
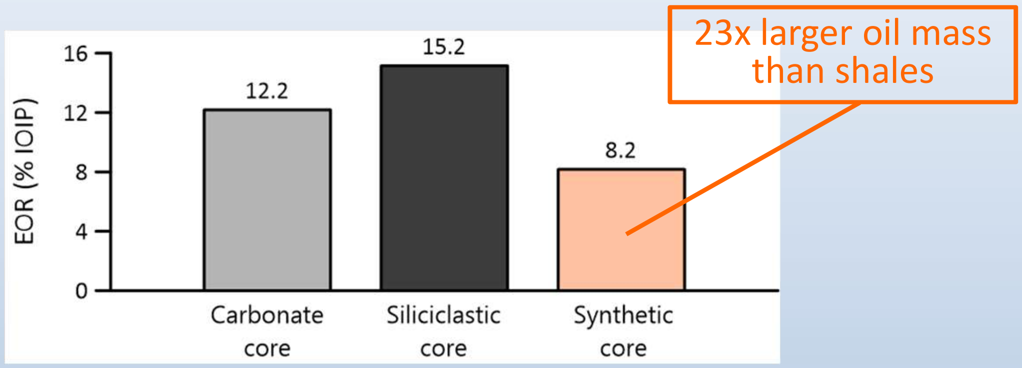
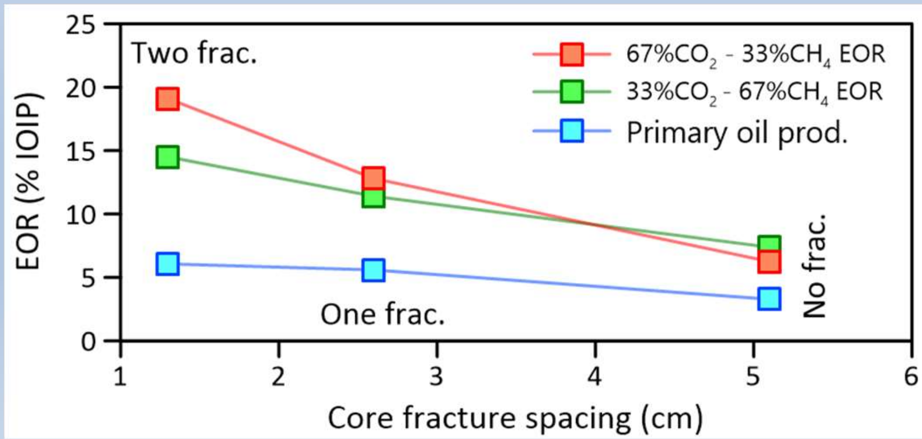


CO_2 - CH_4 EOR Performance

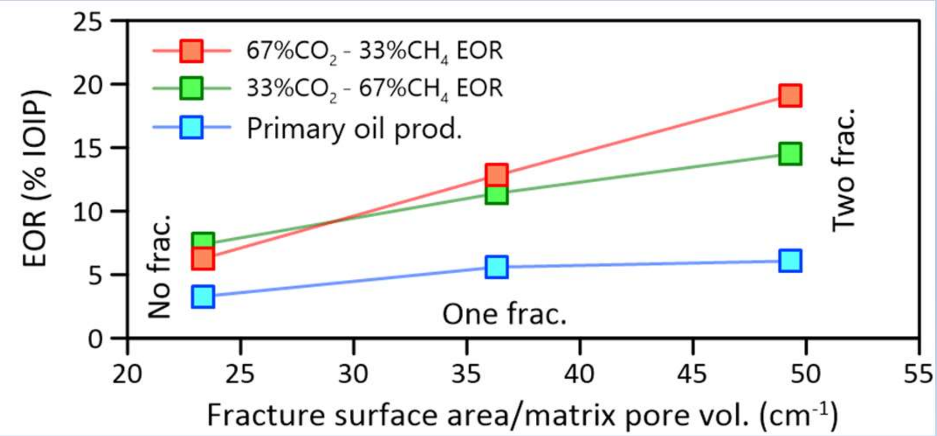
EOR in all cores



EOR vs. shale frac. spacing



EOR vs. shale frac. SA/matrix PV



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Conclusions

- Increasing the number of **fractures in cores promotes larger oil recoveries** both in depletion drive and in the 'huff-n-puff' process.
- Gas injection EOR oil recovery is the result of **favorable interface mass transfer** of gas components into *n*-dodecane across the fracture-matrix interface.
- **CO_2 gas yielded a superior gas injection EOR efficacy** as compared to the hydrocarbon gas.
- Synthetic cores produced much larger EOR oil than the carbonate cores because of favorable pore structure and pore connectivity.
- The results of this laboratory study are consistent with the results from numerical modeling and field pilot projects—indicating that increasing the number of interconnected fractures in the field promotes increased oil recoveries in unconventional reservoirs.

Acknowledgement

The authors are grateful to the support from **Marathon Center of Excellence for Reservoir Studies (MCERS)**; **Mudrocks and Tight Oil Characterization Consortium (MUDTOC)**; and **Reservoir Characterization Project (RCP)** at Colorado School of Mines.

We are also grateful to the **Lawrence Berkeley National Laboratory (LBNL)** for providing us the opportunity to work on this project via the funding provided by the U.S. DOE Contract No. DE-ESD14089.

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Spring 2022

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