Water Conformance and Mobility Control by CO$_2$ Exsolution

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June 5, 2013
Imbibition

Ca~10^{-7}

water (white)

mineral oil (gray)

1000 μm
Water Mobility Control by CO$_2$ Exsolution

(1) Deliver CO$_2$ to flooded zones by carbonated water injection;

(2) Drop pressure $\rightarrow$ CO$_2$ exsolves and plugs established flow paths;

(3) Establish new flow paths.
Microscopic Observation

Schematic of Pore Structure and Micromodel Configuration

Evolution of Exsolved Bubbles in Porous Medium

Zuo et al. (2013) AWR
Microscopic Observation

Illustration of Water Conformance at 650psi pore pressure and 45°C:

- constant upstream injection, 1m/day (CA~10^{-7})
- constant production pressure, 150psi below saturated pressure.
Coreflooding Experiments

Aluminium Core Holder

Experimental Apparatus

System Schematic
Coreflooding Experiments

Normalized Porosity Distribution

- $\Phi=19\%$, $k=470\text{MD}$
- $\Phi=16\%$, $k=35\text{MD}$
- $\Phi=24\%$, $k=28\text{MD}$

CO$_2$ saturation vs Pore pressure [psi]
- High Perm Berea SS
- Medium Perm Berea SS
- Mt. Simon SS

Pressure Drop [psi] vs Injection Rate [mL/min]
- Low Perm Berea SS
- High Perm Berea SS
- ~100 psi/hr
- ~10 psi/hr
Gas Mobility

\[ IFT_{C1/C5} = 0.2\text{~}1 \text{ mN/m} \]
\[ IFT_{CO2/water} = 30\text{~}50 \text{ mN/m} \]

Viscosity_{oil} \gg \text{Viscosity}_{water}

\[
P_{c,f} = \frac{2\sigma}{r_3}
\]
\[
P_{c,t} = \frac{\sigma}{r_1} - \frac{\sigma}{r_2}
\]
\[
P_s = P_{c,f} - P_{c,t}
\]

Roof (1970)


**Zuo et al. (2013) *AWR*
Coreflooding Experiments

Berea Sandstone: ~500mD, ~20% porosity;
Mineral Oil: ~60cSt @50°C
Injection: pre-equilibrated carbonated water, CA~10^{-7}

CWI@1500psi
CWI@600psi

-150psi/hr

![Graph showing recovery factor and water cut](image)
Coreflooding Experiments

Berea Sandstone: strongly oil-wet by cooking with oil

- Carbonated water injection at 1500psi
- Pressure transition from 1500psi to 600psi
- Carbonated water injection at 600psi

Recovery Factor vs. PVI

Water Cut vs. PVI

10-15%
Coreflooding Experiments

Berea Sandstone: water-wet

- Carbonated water injection at 1500psi
- Pressure transition from 1500psi to 600psi
- Carbonated water injection at 600psi
Summary

- Snap-off is favorable in CO$_2$/water systems which produces dispersed gas phase with low mobility;

- Water conformance can be achieved locally and water mobility reduction is sustainable;

- Effective local mobility control can be provided by CO$_2$ exsolution to enhance oil recovery during or after water flooding.

ACKNOWLEDGEMENTS:
This work is funded by the Global Climate and Energy Project (GCEP) at Stanford University;
The micromodel experiments were conducted in the Environmental Molecular Sciences Laboratory (EMSL), a user facility located at Pacific Northwest National Laboratory (PNNL).
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Solution Gas Drive

Nucleation:

\[ \frac{2\sigma \cos \theta}{r_c} = KC_\infty(t) - P_l(t) \]

Diffusion:

\[ z\left(\frac{M_w}{RT}\right) \frac{d}{dt}(P_l V_g) \approx 4\pi \lambda R_j D(C_\infty - C_j) \]

- \( IFT_{C1/C5} = 0.2 \sim 1 \text{ mN/m} \)
- \( IFT_{CO2/water} = 30 \sim 50 \text{ mN/m} \)

Rate Dependent Gas Saturation Profile and Mobility

Scherpenisse et al. (1994)
Tsimpanogianis and Yortsos (2002)