An Experimental Study on the Flood Characteristic and Fluid Rock Interactions of a Supercritical CO₂, Brine, Rock System*

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Abstract

The South West Hub Project is an Australian government-funded initiative in partnership with major local industrial CO₂ emitters. The project aims to reduce emissions by storing commercial quantities of CO₂ in a deep saline aquifer, the Triassic Lesueur Sandstone, located in the Perth Basin of Western Australia. This research investigated the multiphase flow characteristics of the Supercritical CO₂ (scCO₂)-brine-rock system pertinent to the potential storage interval. Core-flooding experiments were conducted on four representative core plugs from the Harvey-1 well. The experiments were performed using a conventional unsteady-state procedure to obtain relative permeability and residual saturation measurements. Fluids used during the experimental work consisted of dead formation brine, CO₂-saturated brine and vapour-saturated scCO₂. Experimental pressure, temperature and brine salinity values were chosen to match the in-situ ones at the sample depths. Petrophysical measurements were carried out on the samples before and after core-flooding (i.e. helium porosity-permeability; pore size distribution by nuclear magnetic resonance (NMR); microstructural and mineralogical investigations) to assess any potential alteration of the samples induced by the flooding procedure. Results show that porosity is not affected by the flooding procedure, but permeability values significantly differ before and after flooding, causing reductions of 25% to 60%. Formation damage (e.g., fines migration) caused by presence of clay minerals in sample pore space may induce unusually low end-point relative permeability values measured at the end of the primary imbibitions. The fines migration hypothesis is supported by NMR measurements performed on two of the samples before and after core-flooding. These indicate a negligible variation of total porosity (also indicated by Helium measurements), but a significant difference in the distribution of pore size compatible
with the occlusion of larger pores by the fines dislodged by the fluids flowing through the pore space. Note that the migration of any fines, which may result in blockage and/or bridging of the pore throats, may intensify the snap-off trapping mechanism and consequently cause residual scCO2 saturation measurements to be abnormally high. The residual scCO2 saturations for all the samples tested here are within the range of 23%–43% which are to some extent higher than expected for their respective permeability ranges.

Reference Cited


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Ali Saeedi$^a$, Claudio Delle Piane$^b$, Lionel Esteban$^b$, Linda Stalker$^b$

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Intro

South West Hub Project*: Government funded initiative aiming to reduce emissions by storing commercial quantities of CO$_2$ in a deep saline aquifer

Triassic Lesueur Sandstone, located in the Perth Basin of Western Australia

* Stalker et al. (2015)
Motivation and methodology

- Project is focused on residual trapping (trapping of CO$_2$ blobs by capillary forces)
Motivation and methodology

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- Focus on multiphase flow characteristics of the scCO₂-brine-rock system
Motivation and methodology

- Project is focused on residual trapping (trapping of CO₂ blobs by capillary forces)

- Focus on multiphase flow characteristics of the scCO₂-brine-rock system

- Core-flooding experiments to obtain relative permeability and residual saturation measurements

- Petrophysical measurements before and after core-flooding:
  - Gas porosity-permeability;
  - Pore-size distribution by nuclear magnetic resonance (NMR)

- Microstructural and mineralogical characterization
Harvey 1 well

Olierook et al., 2014
Samples

<table>
<thead>
<tr>
<th>XRD Mineralogy (wt %)</th>
<th>Quartz</th>
<th>K-feldspar</th>
<th>Kaolin</th>
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<table>
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<th>XRD Mineralogy (wt %)</th>
<th>Quartz</th>
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<th>XRD Mineralogy (wt%)</th>
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<th>K-feldspar</th>
<th>Kaolin</th>
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<tbody>
<tr>
<td></td>
<td>90</td>
<td>8</td>
<td>2</td>
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</tbody>
</table>
Samples

- Quartz
- K feldspar
- Chlorite
- Illite
- Kaolinite
- Al oxide
- Mica
Experimental conditions

**Fluids:**
- Reconstituted brine
- CO$_2$-saturated brine
- Vapour-saturated scCO$_2$
Experimental conditions

Fluids:
- Reconstituted
- CO$_2$-saturated brine
- Vapour-saturated scCO$_2$

P T and salinity:
- Pore pressure & temperature estimated from surveys in Harvey-1
- Overburden pressure calculated from a pressure gradient of 25MPa/km (1PSI/ft)
- Salinity inverted from resistivity logs run in Harvey-1
Experimental procedure

Standard unsteady-state flooding procedure:

1. Vacuum sample for at least 15 hours
2. Brine saturation for at least 24 hours under in-situ conditions
Experimental procedure

Standard unsteady-state flooding procedure:

- Vacuum sample for at least 15 hours
- Brine saturation for at least 24 hours under in-situ conditions
- Multi-rate brine permeability measurement using CO$_2$-saturated brine under in-situ conditions
Experimental procedure

Standard unsteady-state flooding procedure:

- Vacuum sample for at least 15 hours
- Brine saturation for at least 24 hours under in-situ conditions
- Multi-rate brine permeability measurement using CO$_2$-saturated brine under in-situ conditions
- *Primary drainage flood:* displace CO$_2$-saturated brine with vapour saturated scCO$_2$
Experimental procedure

Standard unsteady-state flooding procedure:

- Vacuum sample for at least 15 hours
- Brine saturation for at least 24 hours under in-situ conditions
- Multi-rate brine permeability measurement using CO₂-saturated brine under in-situ conditions
- **Primary drainage flood**: displace CO₂-saturated brine with vapour saturated scCO₂
- **Primary imbibition**: displace vapour-saturated scCO₂ with CO₂-saturated brine
Experimental procedure

Standard unsteady-state flooding procedure:

- Vacuum sample for at least 15 hours
- Brine saturation for at least 24 hours under in-situ conditions
- Multi-rate brine permeability measurement using CO$_2$-saturated brine under in-situ conditions
- **Primary drainage flood**: displace CO$_2$-saturated brine with vapour saturated scCO$_2$
- **Primary imbibition**: displace vapour-saturated scCO$_2$ with CO$_2$-saturated brine
- **Secondary drainage**: for the 2$^{nd}$ time, displace CO$_2$-saturated brine with vapour-saturated scCO$_2$
Results
Results: relative permeability primary drainage flood

<table>
<thead>
<tr>
<th>Depth, m</th>
<th>Pore pressure (MPa)</th>
<th>Overburden pressure (MPa)</th>
<th>Temperature (°C)</th>
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<tbody>
<tr>
<td>1,901.6</td>
<td>19.05</td>
<td>43.02</td>
<td>60.7</td>
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<td>2,491.6</td>
<td>24.95</td>
<td>56.36</td>
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<td>1,935.5</td>
<td>19.39</td>
<td>43.78</td>
<td>61.2</td>
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</table>
Results: residual saturation

**Graph 1:** Initial gas permeability [mD] vs. Residually trapped CO$_2$ [%]

**Graph 2:** Modal pore throat size [μm] vs. Residually trapped CO$_2$ [%]
Results: residual saturation

Pore throat size range from MICP

Modal pore throat size [μm]
Results: Petrophysical changes

Porosity before CF vs. Porosity after CF for samples 206647, 206660, and 206669.
Porosity remained unchanged but **permeability decreased by 25%-51%**
Results: Petrophysical changes

NMR T2 distributions in brine-saturated samples before and after core-flooding tests

Distribution shifted towards smaller pore sizes although the integrated total porosity is virtually unchanged.
Discussion: fluid rock interaction

500-1000mL of fluids recovered

Possible dissolution of minerals;

Geochemical modelling supports precipitation of dawsonite: $\text{NaAlCO}_3(\text{OH})_2$
Discussion: fines migration (?)
Conclusions

• Relative permeability and residual CO₂ saturation experimentally measured on 3 samples from the SW-Hub at in-situ conditions;

• Residual saturation were relatively high (23-43%), inversely proportional to the samples’ permeabilities and modal pore throat size;

• Samples lost 25%-51% of their original permeability as a results of the fluid-rock interactions during core-flooding tests;

• Pore-size distribution inferred from NMR indicates a shift towards smaller pore size although the total porosity remains the same;

• Effluent and geochemical analysis support the precipitation of dawsonite and mobilization of fines (kaolinite) as possible mechanisms to explain the observed degradation of permeability
Outlook

3 more wells drilled in the SW-Hub to test:

• Injectivity potential in the Wonnerup;
• Containment potential in the Yalgorup
Outlook

3 more wells drilled in in the SW-Hub to test:

• Injectivity potential in the Wonnerup;
• Containment potential in the Yalgorup

Ongoing research focused on fluid-rock interactions:
• Systematic sampling of fluids during core flooding;
• Systematic assessment of mineralogy variations;
• In-situ visualization using X-ray μCT;
• Focus on in-situ brine salinity
Acknowledgements
Thanks

**Experimental data:**

**Geochemical data:**

**Geological core description, mineralogy and diagenesis:**
Results

- Change in porosity and permeability of a different sample from Lesueur Formation taken from Pinjarra-1 after undergoing the flooding procedure:

- Porosity remained unchanged but permeability increased by more than 300%.