Multi-phase flow experiments of CO₂ and brine in reservoir rocks
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CASE 1: heterogeneity effect

**EXPERIMENTAL PROCEDURE**

- **INJECTION**
  - Pump C injects fluids continuously and refills automatically.
  - Maximum pressure: 3750 psi.

- **CORE**
  - 8.5 cm long, 5.08 cm diameter.
  - Porosity: 21.31%, 24.02%, 28.19%, 31.46%.
  - Flow rate: 1 mL/min.
  - Temperature and confining pressure vary during injection experiments.

- **SEPARATOR**
  - 15.24 cm long.
  - Rated to 3000 psi, 100°C.

**Thermophysical properties of brine and CO₂**

- **BRINE**
  - Composition: 6g/L NaCl + 0.5g/L CaCl₂.
  - Temperature: 5°C, 33°C, 5°C.

- **CO₂**
  - Composition: 5% 21% 34% CO₂.
  - Flow rate: 1 mL/min.

**CONCLUSIONS**

- The sample is very heterogeneous with little variation of porosity along the core and no visible structure. The less porous layers are hardly invaded.
- When the sample is homogeneous and the injection flow rate is low enough, gravity effects become important and the CO₂ invades preferentially the top part of the core.
- CO₂ saturation and relative permeability are seen to be flow-rate dependent. At higher flow rate, CO₂ saturation is higher and relative permeability lower.

**CASE 2: flow rate effect**

- **EXPERIMENTAL PROCEDURE**
  - Temperature: 5°C.
  - Gas composition: 13% CO₂, 14% H₂S, 1% H₂, 5% Ar.

- **CORE**
  - Sample: Berea Sandstone 2.6 cm long, 6.35 cm diameter.
  - Porosity: 21.31%, 24.02%, 28.19%, 31.46%.

- **SEPARATOR**
  - 15.24 cm long.

**Effect on CO₂ Saturation for different Injection rate**

- Flow rate: 0.5, 1, 2 mL/min.

**CONCLUSIONS**

- The rock is very heterogeneous with a structure composed of successives layers that are not parallel to the main axis of the cylinder.
- Contrarily to the widely accepted theory, the CO₂ saturation is a function of the total flow rate. As a consequence, the relative permeability varies with flow rate.

**CASE 3: Gravity effect**

- **EXPERIMENTAL PROCEDURE**
  - Temperature: 63°C.
  - Pump D applies confining pressure around the core.

- **CORE**
  - Porosity: 37.50%, 39.76%, 29.32%, 35.42%.
  - Flow rate: 1 mL/min.
  - Drainage of CO₂ is progressively increased.

**Thermophysical properties of CO₂ and brine**

- **BRINE**
  - Composition: 10g/L NaCl.
  - Temperature: 5°C.

- **CO₂**
  - Composition: 5% 20% 25% CO₂.
  - Flow rate: 1 mL/min.

**CONCLUSIONS**

- The rock is very heterogeneous with a structure composed of successives layers that are not parallel to the main axis of the cylinder.
- Contrarily to the widely accepted theory, the CO₂ saturation is a function of the total flow rate. As a consequence, the relative permeability varies with flow rate.

**INTRODUCTION / BACKGROUND**

Relative permeability is a key concept for carbon dioxide storage. Defined in multi-phase flow in porous media as the ratio of effective permeability of a particular fluid at a particular saturation to absolute permeability of that fluid at total saturation, relative permeability controls the majority of the phenomena that are met when two (or more) fluids are flowing through rocks.

Studying the relative permeability properties of the CO₂ brine system in deep saline aquifers is fundamental to answer important questions that are met in the field, for instance:

- What should be the pressure in the injection zone?
- How fast would CO₂ leak up a fault under buoyancy?
- How to maximize sweep efficiency (storage capacity)

In the laboratory, relative permeability experiments associated with fine rock characterizations are performed in order to address more fundamental issues. For instance:

- What are the trapping mechanisms?
- How do the external factors influence relative permeability (pressure, temperature, injection rates, rock properties/structure)?

**Multi-phase flow in reservoir rocks**

Studying relative permeability properties of CO₂ and brine in reservoir rocks is of major importance for carbon sequestration. In the lab, we see that:

- When the core is structured, the heterogeneities are controlled the useful distribution of CO₂ at steady state. The less porous layers are hardly invaded.

The sample is very heterogeneous with little variation of porosity along the core and no visible structure. The less porous layers are hardly invaded.

When the sample is homogeneous and the injection flow rate is low enough, gravity effects become important and the CO₂ invades preferentially the top part of the core.

CO₂ saturation and relative permeability are seen to be flow-rate dependent. At higher flow rate, CO₂ saturation is higher and relative permeability lower.

Numerical simulations are underway to validate these observations (see Chia-Wei Kuo's poster) as well as sub-core scale analysis (see Michael Krause's poster).