Foam flow in fractured media

Markus Buchgraber, Monrawee Pacharoen, Anthony Kovscek, Louis Castanier
Thanks to Martin Ferno
Carbon Capture and Sequestration

Overview of Geological Storage Options
1. Depleted oil and gas reserves
2. Use of CO₂ in enhanced oil and gas recovery
3. Deep saline formations - (a) offshore (b) onshore
4. Use of CO₂ in enhanced coal bed methane recovery

Saline Aquifers
1000-10000 Gt

Oil and Gas Reservoirs
680-900 Gt

Coal
15-200 Gt
Why Foam?

- Mobility control of injected gases
- EOR and CO2 sequestration
- Mitigate extreme permeability contrasts
- Better economics
Upscaling - Problem

Pore

Core

Field
How Can We Use Micromodels

- Micro observation of flow behavior and saturation changes-left
  Polymer/Oil Imbibition @ 1ft/day
  Mobility Ratio = 17

- Macro observation of displacement patterns-all
  Carbonate MM
  Water- Hentane
From Rock to Micromodel

SEM image of Berea Sandstone

Digitized Berea SEM image

Micromodel

Etched Silicon Wafer
Micromodel Portfolio

Sandstone- 1
- 22% Porosity
- 900 mDarcy
- 30-300μm grains
- 500,000 pores
- 0.01 ml volume
- 25 μm grain depth

Sandstone -2
- 54% Porosity
- 3000 mDarcy
- 125-250μm grains
- 0.0245 ml volume
- 25 μm grain depth

Carbonate
- 45% Porosity
- 400 mDarcy
- 2.5-800μm grains
- 0.012 ml volume
- 14 μm grain depth
Fracture micromodel designs
Foam Flow for Enhanced Oil Recovery
Fracture characterization
Various types of foams
Foam in Simplified Systems

- Foam resistance in porous media reaches a constant due to limiting capillary pressure.
- Fracture foam flow resistance increases monotonically and reaches a constant at very large $f_g$. 

Hirasaki and Lawson (1985)
Set up schematic
Physical Model vs. Experimental Result

Steady-state foam flow predicted by the full physics model in porous media

Experimental Results of a 40μm smooth fracture

Pressure Gradient [kPa/cm]  Pressure Drop [psi]
Checkerboard pressure data
In situ foam generation
Changes in foam texture
Fractured cores set up

- **Mass flow controller**
- **Sandstone Pregenerator**
  - Pre-generated foam
- **Visualization Cell**
- **Surfactant Solution Pump**
- **N₂**
- **PC**
- **Pressure transducer**
- **Waste**

**Fractured core**
- 6.6 cm diameter × 15 cm length
- Broken by a hammer to create rough surface fractures
- Estimated aperture ~ 63 μm
- Foam texture decreases with increasing foam quality
- No foam generation or coalescence observed within the smooth fracture.
Results rough fracture

- Pressure response is insensitive to liquid flow rate for the wet foam.
- At very high gas fractional flow, foam starts collapsing and the measured pressure drop declines drastically.
Foam and gas flow

Fracture is fully filled with foam while it is only partially filled during $N_2$ flood.
• Foam quality and fluid flow condition affect bubble configurations and flow resistance in smooth fractures.

• In rough fractures, foam resistance increases as foam quality increases. The resistance drops drastically at the foam quality of 99 - 99.5% due to high local capillary pressure.

• Foam has ability to divert injected fluids from fractures into rock matrix. This ability is affected by the contrast between fracture and matrix permeabilities.
Current Applications

• Gas injection in Carbonate reservoirs offshore Mexico
• CO2 injection for EOR USA
• CO2 sequestration projects planned
• Steam foam