Foam Generation and Coalescence in Micromodels

Muhammad Almajid

Stanford Center for Carbon Storage Annual Meeting
May 27th-28th, 2015

Outline

- Motivation
- How is foam relevant to CCS?
- Experimental procedures
- Foam generation
- Foam-oil interactions (coalescence)
- Conclusion
Motivation

- **EOR by gas injection**
  - Gravity segregation
  - Viscous fingering

- **Foam provides mobility control**
  - Mobility Ratio $= \frac{k_{rg}/\mu_g}{k_{ro}/\mu_o}$
  - Increases gas apparent viscosity, $\mu_g$
  - Foam traps gas – reduces $k_{rg}$ significantly
  - Stability of foam dictates whether mobility control is achieved or not
  - Rates of generation and coalescence are crucial for population balance modeling

---

How is foam relevant to CCS?

**Improved aquifer utilization**

**Reduced carbon footprint**

Gas Saturation (1/4 five spot)

Gas Saturation (1/4 five spot)


**Definition of Foam**

- Dispersion of non-wetting fluid (gas) in wetting fluid (foamer solution)

*Courtesy: Kovscek and Radke, 1993

---

**Experimental Procedures**

- Foamer solution: 0.5 wt% NaCl, 0.5 wt% surfactant (Sodium C14-16 Olefin Sulfonate or Stepan-40) in DI water

- Foam generation experiments
  - Fully saturated foamer solution MM
  - Co-inject N₂ + foamer solution

- Oil-foam interaction experiments
  - Initialization of waterflood Sₚ₀
  - Co-inject N₂ gas + foamer solution

*Courtesy: Inwood, 2008
Foam Generation

(Ranosohoff and Radke, 1986)

1. Snap-off
   › Most dominant?

2. Lamella division
   › Most dominant?

3. Leave behind – “weak” foam
No “Critical” Velocity Observed

- “Critical” velocity implies that there is a minimum pressure gradient needed for lamella division
- Not observed in our experiments using micromodels

\[ Ca = \frac{u_g \mu_g}{\sigma_{gw}} \]

<table>
<thead>
<tr>
<th>q_w (ml/min)</th>
<th>f_g</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>89%</td>
</tr>
<tr>
<td>0.01</td>
<td>90%</td>
</tr>
<tr>
<td>0.01</td>
<td>92%</td>
</tr>
</tbody>
</table>

Foam Coalescence: Oil Effects on Foam
Foam vs. residual oil in porous media

1. Bypassed oil
   a) Lamella moving across a non-wetting discontinuity
   b) Trapped gas saturation

2. Snapped-off oil
   a) Hindered generation
   b) Trapped gas saturation

Lamella and bypassed oil (coalescence)
- $E_{o/w} > 0$ and $B > 0$
- Coalescence keeps occurring until stable pseudoemulsion film is formed

Proposed pinch-off mechanism by Myers and Radke (2000):
Lamella moves with no coalescence

- After oil surface is coated with surfactant→ lamella moves with no coalescence
- Another way oil is produced: transported in the Plateau borders

Hindered Generation

- Roof snap-off vs. foam generation snap-off
- Observed generation and immediate rupture in some germination sites where oil is not displaced
Trapped Gas

- $k_{rg}$ depends on the amount of trapped gas
- With oil trapped $\rightarrow$ less places for gas to be trapped $\rightarrow$ more flow paths and vice versa

Before most trapped oil is displaced:  
After most trapped oil is displaced:

Conclusion

- Pore-level mechanisms improve our ability to model foam
- No “critical” velocity was observed in foam generation
- For an entering and bridging system, pinch-off is observed for the first time in micromodels
- A new mechanism was identified and termed “hindered snap-off”
- Oil-in-water and water-in-oil emulsions were repeatedly observed and they directly influence foam generation processes
Future Work

- Effect of surfactant chain length on the size of the emulsions
- Sand pack experiments to study foam generation more thoroughly
- Hydrodynamic modeling of the hindered snap-off mechanism
- Foam ability to trap gas in the presence of oil needs to be characterized