Foam Generation and Coalescence in Micromodels

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Outline

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

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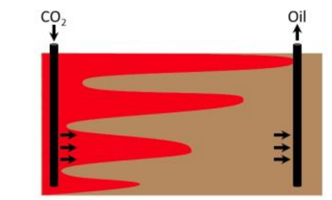
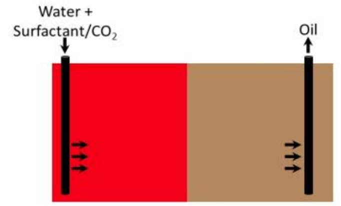
Motivation

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



- **Foam provides mobility control**
  - $\text{Mobility Ratio} = \frac{k_{rg}/\mu_g}{k_{ro}/\mu_o}$
  - Increases gas apparent viscosity, μ_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



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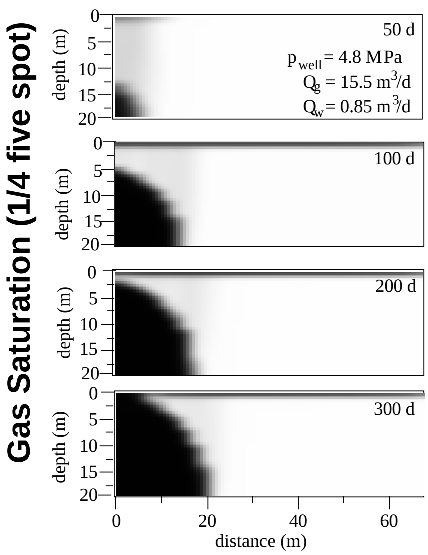
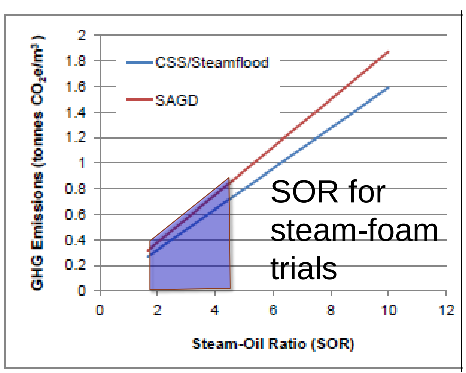
How is foam relevant to CCS?

Improved aquifer utilization



Reduced carbon footprint



Boone, T.J., Sampath, K. and Courtnage, D.E., Paper WHOC12-412 presented at the 2012 World Heavy Oil Congress, held in Aberdeen, UK.

Kovscek, A. R., T. W. Patzek, and C. J. Radke.] *Society of Petroleum Engineers Journal*, **2(4)**, 511-526 (1997).

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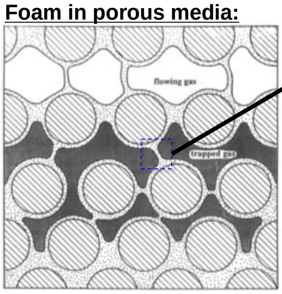
Definition of Foam

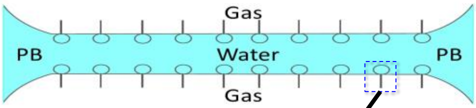
- Dispersion of non-wetting fluid (gas) in wetting fluid (foamer solution)

Lamella:

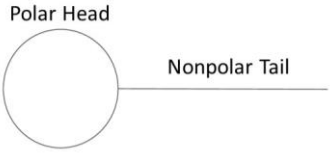
Foam in porous media:



*Courtesy: Kovscek and Radke, 1993



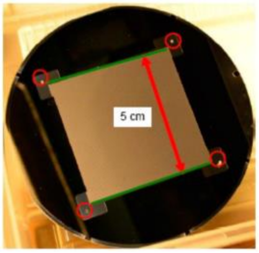
Surface active agent:



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 N_2 + foamer solution
- Oil-foam interaction experiments
  - Initialization of waterflood S_{or}
  - Co-inject N_2 gas + foamer solution

Micromodel:



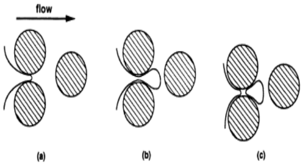
*Courtesy: Inwood, 2008

Foam Generation

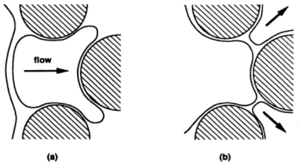
Foam Generation

(Ranosohoff and Radke, 1986)

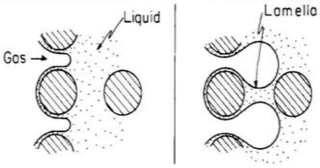
1. Snap-off
   - Most dominant?



2. Lamella division
   - Most dominant?



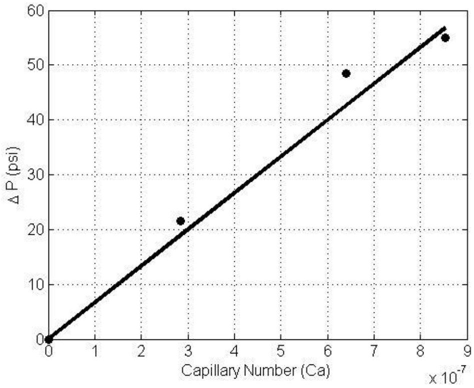
3. Leave behind – “weak” foam



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
- $Ca = \frac{u_g \mu_g}{\sigma_{gw}}$

q_w (ml/min)	f_g
0.005	89%
0.01	90%
0.01	92%



Foam Coalescence: Oil Effects on Foam

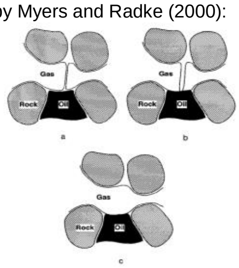
Foam vs. residual oil in porous media

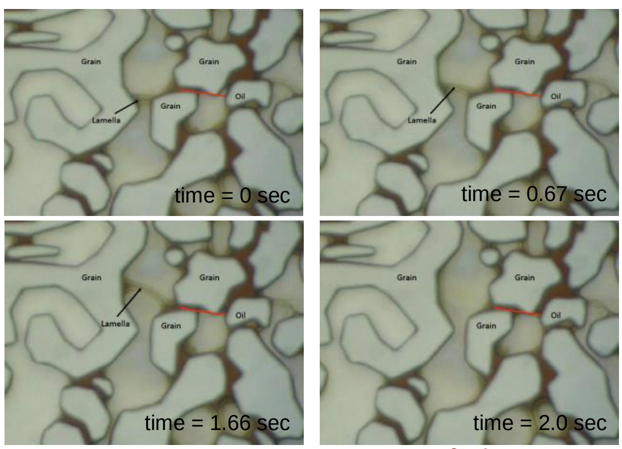
1. Bypassed oil
   a) Lamella moving across a non-wetting discontinuity
   b) Trapped gas saturation
2. Snapped-off oil
   a) Hindered generation
   b) Trapped gas saturation

Lamella and bypassed oil (coalescence)

- $E_{o/w} > 0$ and $B > 0$
- Coalescence keeps occurring until stable pseudoemulsion film is formed

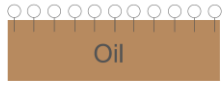
Proposed pinch-off mechanism by Myers and Radke (2000):

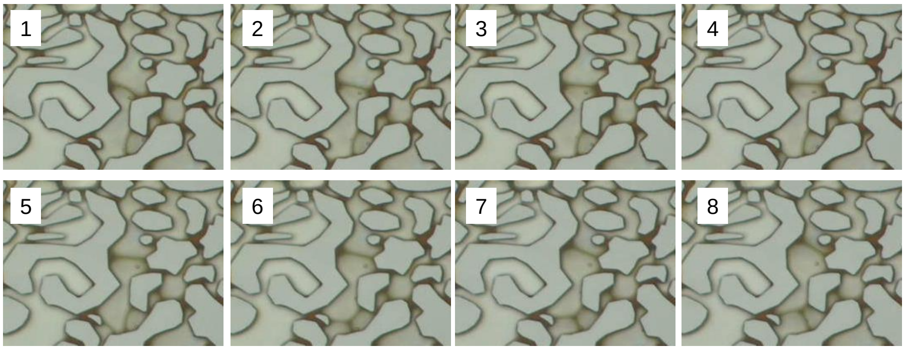




Lamella moves with no coalescence

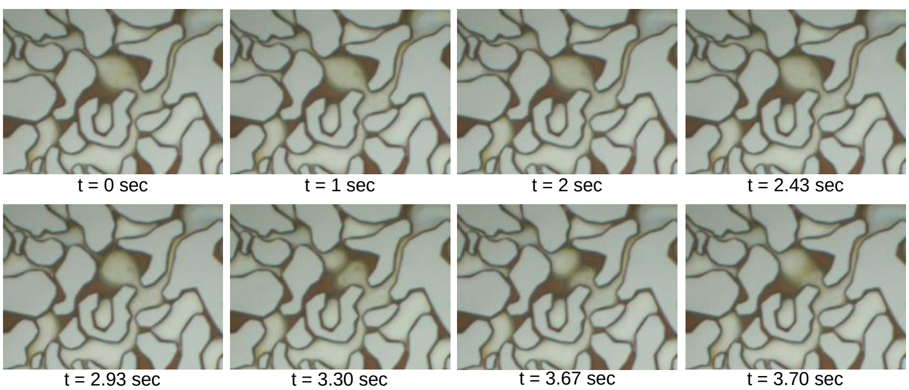
- After oil surface is coated with surfactant→ lamella moves with no coalescence
- Another way oil is produced: transported in the Plateau borders





Hindered Generation

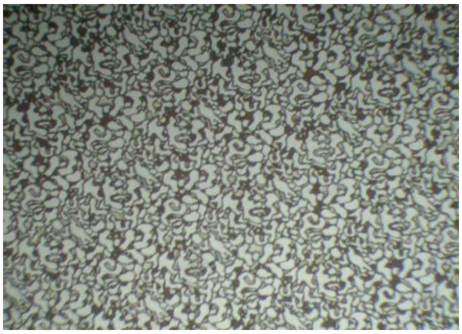
- Roof snap-off vs. foam generation snap-off
- Observed generation and immediate rupture in some germination sites where oil is not displaced



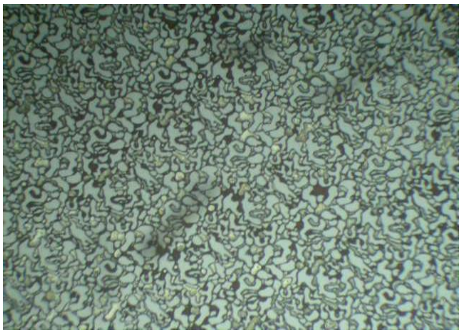
Trapped Gas

- k_{rg} depends on the amount of trapped gas
- With oil trapped → less places for gas to be trapped
  → 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