Bubble Motions in Bubble Rafts under Steady Shear

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Supported by: Department of Energy grant DE-FG02-03ED46071, Sloan Foundation, Petroleum Research Fund, and UCI UROP
General Outline

• Initial results
• Overview of the system
• Questions raised/addressed in this talk
Two Questions

• What is the average flow behavior of slowly sheared bubble raft? (How does this relate to flow of foams?)

• What is the connection between average flow behavior and individual bubble motions?
General properties

• Fluctuations in stress/energy.

• “Particle” rearrangements (T1 events, non-affine motions)

• Non-uniform shear

• Diffusive motion of “particles”.
Two “types” of non-uniform shear

Non-uniform shear: region of non-zero and zero shear rate coexist

1) strain rate is continuous (usually exponential velocity).

2) strain rate is discontinuous.
“Two-dimensional” foam

Debregeas, Tabuteau, Di Meglio, PRL 87 (2001)
Three dimensional suspension

Definition of T1 Event

T1 event:

Neighbor switching
Apparatus
Schematic of Apparatus

Inner radius $r_i$: 3.84 cm
Outer radius $r_o$: 7.43 cm
Area fraction: 0.95
Boundary conditions: no slip at both walls, but inner cylinder is free to move.
Definition of Terms

Outer barrier moves with \( V \)

**Strain:** \( \gamma = \Delta x / \Delta r \)

**Strain Rate:** \( d\gamma / dt = v / \Delta r \)

\[
d\gamma / dt = r \frac{d}{dr} \left( \frac{v(r)}{r} \right)
\]

**Viscosity:** \( \eta = \text{stress} / (\text{strain rate}) \)

**Shear stress:** \( \sigma_{xy} = F / L \) (two-dimensions)
Bubble Motions
Reminder of Geometry Consequences

- **Couette Geometry**: average stress, $\sigma$, proportional to $1/r^2$

- **Yield stress**, $\sigma_y$: $\sigma(\dot{\gamma}) = \sigma_y + \mu\dot{\gamma}^n$

  $=>$ critical radius beyond which "rigid" body or elastic behavior, strain rate is a continuous function of $r$. 
Effective Viscosity: stress/(strain rate)

\[ \sigma = \sigma_y + a (d\gamma / dt)^{1/3} = (0.8 \text{ mN/m}) + (1.8 \text{ mNs}^{1/3}/\text{m})(d\gamma / dt)^{1/3} \]
Stress versus strain

(1) strain rate = 3 x 10^{-2} \text{ s}^{-1} (2) strain rate = 4 \times 10^{-3} \text{ s}^{-1}

\sigma_y = 0.8 \text{ mN/m}

r_c = 6.3 \text{ cm}

r_c = 6.7 \text{ cm}
Average Velocity Profile

\[ \frac{V(r)}{\Omega r} = 1 \implies \text{rigid body rotation.} \]

Fit is to vel. profile for a power law viscosity.

\[ \frac{v(r)}{\Omega r} \]

radial position (cm)
Some Questions

• What sets the “critical” radius?
• Why is strain rate discontinuous?

Consider “flow” during individual events and T1 events.

• What is the role of stress chains, if they exist?
T1 events and stress

![Graph showing stress (dyne/cm) vs. radial position (cm)]
T1 events and bubble motions
“Local” Displacements

\[ \Delta \theta / (\Omega \Delta t) \]

radial position

A, D
B, C
E
T1 events and average velocity

<table>
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<th>radial position (cm)</th>
<th>v(r)/Ω</th>
<th># T1 events/ bubble</th>
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Summary

• Apparent disagreement between average stress measurements and average velocity profile: strain-rate discontinuity needs to be understood.

• Connection between T1 events and short time bubble motions. Not clear the connection between T1 events and average velocity.

• Time averages rapidly converge despite very nonlinear short time motion.
Acknowledgments

• Video images of bubble raft: John Lauridsen
• Viscosity measurements: Ethan Pratt
• Initial Bubble tracking software: Gregory Chanan
• Funding: Department of Energy grant DE-FG02-03ED46071, Sloan Foundation, Petroleum Research Fund, and UCI UROP

• Video images of bubble raft: John Lauridsen