Mechanism of atomization in a two-layer Couette flow

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Acknowledgments

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Funding:
NASA, μ-gravity;
Importance of gas-liquid flows (and other fluid-fluid flows)

1. Pipeline and process piping flows, energy exchange devices, oil and gas well risers.

2. Process equipment, reactors, absorbers, etc.

3. Environmental flows (ocean surface, clean up of contaminated ground water).
Importance of atomization

In annular flow, the entrained fraction can be 20-40% of the liquid (Fore and Dukler, 1995; Asali et al., 1985).

Current (mostly) empirical correlations are inadequate.

What is known about atomization

Atomization occurs from solitary and roll waves (Woodmansee and Hanratty, 1968; Whalley, Hewitt & Terry, 1979).
Goals of current study

• Use experiments to observe the details of the atomization process.

• Determine the key elements of the atomization mechanism.

• Develop a reasonable theoretical description of this process.

• Talk today will focus on the insight gained about the mechanism from the experiments.
Role of $\mu$-gravity

Atomization occurs only from the largest waves. The wave shape varies significantly with the level of gravity stabilization.

Wave shape as a function of gravity

(Simulation from a wave equation)
Experimental strategy

By using two liquids, instead of gas-liquid, we slow the process down considerably.

Couette device allows (actually requires) matched-density fluids so that there is no overall body force stabilization, this eliminates a parameter.

The Couette geometry allows independent choice of the liquid depths.

We have some range of choice of the viscosity ratio.
Flow geometry of interest

Two-layer, horizontal two-fluid flow
Experimental apparatus

Outside cylinder is Plexiglas®, Inside cylinder is Aluminum painted black

Outside cylinder is rotated.

Torque transducer

Hg Layer

Glycerine-water

Silicone Oil

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NASA Microgravity Conference, August 12-14, 1998
Two-Liquid, Matched density Couette device

(another view)

Couette Cell

Two-layer Couette experiment showing the high speed video camera set-up.
Direct view video of waves in Couette device
Wave regime map for the region where long waves are unstable
Figure 3: A roll wave for $m=0.0159$, $\sigma = 0.01$ $N/m$, $l = 0.66$, and $U_p = 84$ cm/s. (“Dark” phase is more viscous and it is being atomized)

$Re_{\text{light}} = 560 \quad Re_{\text{dark}} = 9.5$
Figure 4: A sheet-like structure for $m=0.0159$, $\sigma = 0.01$ $N/m$, $l = 0.66$, and $U_p = 84$ cm/s. (“Dark” phase is more viscous and it is being atomized)
Figure 5: A sheet-like structure just prior to break off for $m=0.0159$, $\sigma = 0.01 \ N/m$, $l = 0.66$, and $U_p = 84 \ cm/s$. ("Dark" phase is more viscous and it is being atomized)
A series of frames 2 milliseconds apart showing the breakup.
Breakup occurs!!
The change in the height of the sheet \( \frac{d}{d_0} \) as a function of time.

(almost) Linear stretching is observed.

![Graph showing the change in height over time with experimental and theoretical data.](http://www.nd.edu/~mjm/)
Conclusions

1. Roll waves form in the more viscous phase and scale as the depth of this phase.

2. For sufficiently low values of the more viscous phase depth, waves do not attain a large enough amplitude to allow atomization
   - This is analogous to gas-liquid flows for thin liquid films

3. Solitary and/or roll waves can form and persist for long times or evolve into other waves without atomizing
   - This point has not been clear from previous gas-liquid studies where roll waves were assumed to imply atomization.
Conclusions (cont.)

4. Long sheets of liquid can be pulled from the large waves and may break once the elongation is sufficiently large.

At breakup: (for $Re_{\text{inner}} = 560$, $Re_{\text{outer}} = 9.5$)

The Capillary number, $Ca = \frac{\mu U}{\sigma}$ is about 40,
The Weber number, $We = \frac{\rho U^2 d}{\sigma}$, is about 7.

5. Long steady stretching is necessary because our experiments in oscillatory flows do not show atomization even for very high amplitude waves.