"Team Third" Report: Interaction of Water Surface Tension and Detergent Viscosity
MCEN 5151-001 Flow Visualization, Fall 2025
Emma Wilder, 11/08/2025 (created alone)

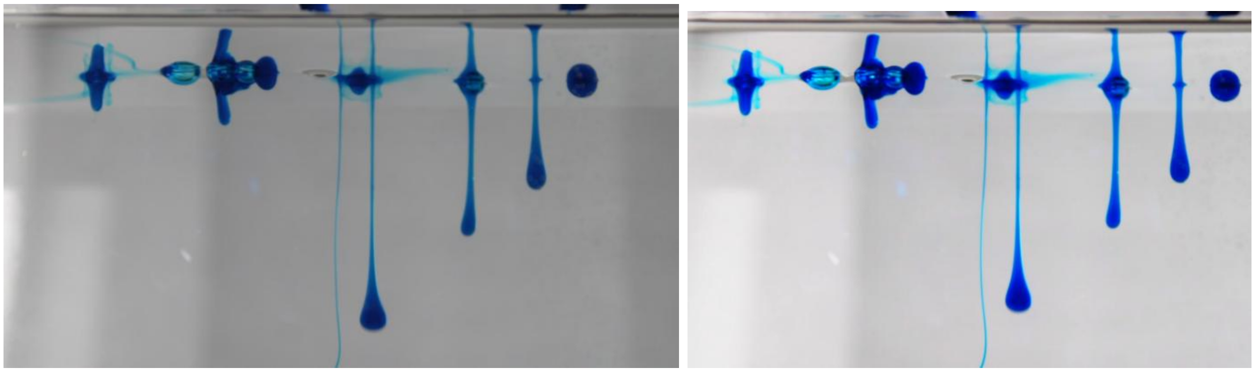

Fig. 1: Thumbnail of (A, left) the unedited video, and (B, right) the edited video.

Introduction

The intent of the video made for Team Third (represented by the thumbnail in Figure 1) was to visualize the resulting instability of placing a viscous fluid on top of water. The long fingers formed by gently placing drops of detergent on the water surface resemble fingers formed from Marangoni bursts (see my Get Wet assignment). I am not aware of this precise phenomenon being visualized before. But the inspiration came from a similar phenomenon I noticed with food dye in Team First where the dye would sit on top of the water and thin strands of dye would form below. However, I wanted to see how this phenomenon would work for a more viscous fluid such as laundry detergent, resulting in the submission shown in Fig. 1.

Flow Apparatus

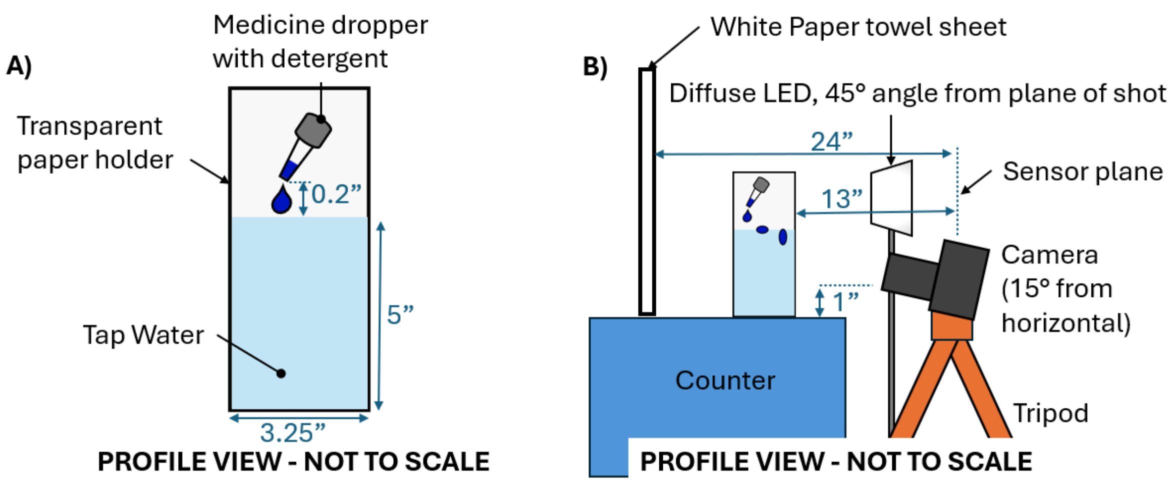

Fig. 2: Profiles of experimental setup including (A) a close up of the vessel, & (B) entire setup.

The vessel used was a transparent paper holder filled with tap water. Around 10 mL of laundry detergent (Tide Original) was mixed with 10 drops of blue food dye (Kroger Food Colors) to enhance color. Droplets of the detergent were then placed gently on the water surface to prevent breaking the surface tension and allow formation of the fingers. Placements and dimensions of supplies used are shown in Fig. 2a-b. The camera placement with a 15-degree angle enabled a view of the water surface from below to see how the fingers formed while showing a reflection of the fingers forming which was interesting visually.

Scientific Explanation

Although there is some resemblance of the droplets and fingers to Rayleigh–Taylor or Plateau-Rayleigh instability, this phenomenon does not seem to explain the flow (i.e., it is just one droplet that does not separate, and it does not start off as a large sheet of liquid on top of another). Instead, it seems to be explained simply by a combination of surface tension, density differences, and viscosity. At room temperature, water has a density of around 998.2 kg/m^3 (Tanaka et al., 2001), but laundry detergent has a higher density of around 1007.0 kg /m^3 (Procter & Gamble). When placing the detergent on the water surface, even though it is denser than water, it appears to be held up by surface tension initially (Fig. 3, Stage 1). However, the density difference results in a sag of the detergent into the water, eventually overcoming the surface tension (possibly aided by the detergent being a surfactant and lowering the surface tension, Fig. 3, Stage 2). During Stage 3, the density of the detergent leads to the droplet falling. However, there appears to be some adhesion of some of the detergent to the water surface. Because the detergent is highly viscous, a long strand of detergent connects the detergent that is adhered to the water surface with the bulk of the detergent that is falling (Fig. 3, Stages 3-5). In Stage 5, most droplets seem to bend to one side. I suspect that this comes from a small degree of non-uniformity in the initial dropping (Stages 2-3), causing uneven flow and pressure, and deforming the droplet more, increasing this deformation and altering the water flow path enough to cause the droplet to rotate more than 90 degrees in some instances (Fig. 3, Stage 5).

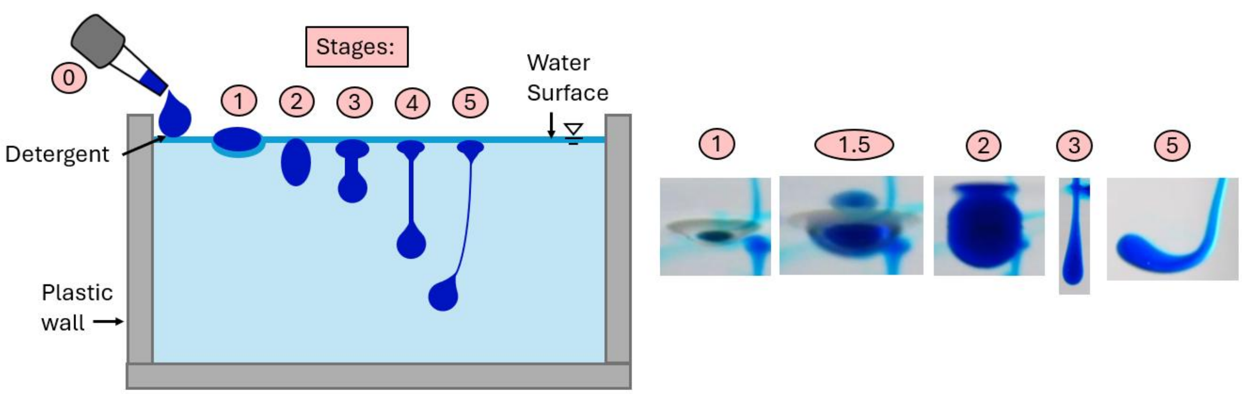

Fig. 3: Progression of detergent fingers forming (Stages 0-5 shown in red circles), with images shown for surface tension breaking during Stage 1 and 2.

Estimation of Velocities and Non-Dimensional Scales

To estimate the velocity and size of the droplets, tracking droplet movement over the frames can be and paired with the size of the field of view. The vertical field of view (FOV) for the video was 2 inches. Tracking one droplet that starts at around 9 seconds into the video, around

¾ of the FOV (around 1.75 inches) in 1.90 seconds. This average velocity is equivalent to 0.92 inches per second or ($2.3*10^{-2}$ m/s). The diameter of the droplets are around 5% of the vertical field of view, or around 1/10 inch ($2.5*10^{-3}$ m). Using these figures with Eq. 1, the Reynolds number (Re) can be estimated at 57.4. This Re is in the laminar range (De Kruijf et al., 2021), but could also have some flow separation. Flow separation or oscillation paired with deformations in the droplet could explain why when the drops reach the bottom of the screen, they bend to one side (Fig. 3, Stage 5).

$$Re = \frac{\rho v D}{\mu} = \frac{(998\,\frac{kg}{m^3})\left(\frac{0.023\,m}{s}\right)(0.0025\,m)}{(0.0010\,Pa*s)} = 57.4 \qquad \text{Equation 1}$$

Using the simplifying assumption that the droplet is a sphere (which is approximately true for the bottom part of the droplet for most of the duration of the drop), the theoretical terminal velocity can also be estimated using Stoke's Law (Sutherland and Tan, 1970; Eq. 2). By comparing this value to the observed velocity, we can understand how much the thin fingers may slow down the detergent droplet. Using the densities of water and the detergent shown above (ρ_w & ρ_d, respectively), the diameter (D) of the droplet determined above, and the viscosity of water (μ), the expected velocity is around 0.25 m/s (Eq. 2). This theoretical velocity is a factor of 10 higher than the observed average velocity ($2.3*10^{-2}$ m/s). Assuming that this average velocity is close to the terminal velocity, the strand coming from the water surface likely slows down the drop significantly because of the high viscosity of the detergent.

$$v = \frac{g(\rho_d - \rho_w)D^2}{18\mu} = \frac{(9.8\,\frac{m}{s^2})(1070\,\frac{kg}{m^3} - 998\,\frac{kg}{m^3})(0.0025\,m)^2}{(18)(0.0010\,Pa*s)} = 0.25\,\frac{m}{s} \qquad \text{Equation 2}$$

Since the vertical resolution is 1080 pixels and the FOV is 2 inches (50.8 mm), one pixel covers around 0.05 mm. The droplets transverse ¾ of the FOV in 1.9 seconds, which means that 40% of the FOV is transversed per second when the drop is moving its fastest. Since the shutter speed is 1/60 second, the shutter is open long enough for the drop to move 0.7% of the FOV, or 0.36 mm. While this choice of shutter speed does result in some minimal motion blur, it also makes the video less jittery because of the 180-degree shutter. This tradeoff was judged to be appropriate for a visually pleasing video without sacrificing much resolution from the motion blur.

Visualization and Photographic Technique

The visualization technique is a marked boundary technique since a dyed detergent is used to distinguish the fluid from the bulk water and the background. Lighting included a nine-inch diffuse LED light panel (NEEWER) positioned at a 45° angle to avoid glare and reflections and was 18 inches away from the container. The light was set to maximum brightness for proper exposure (10 Watt power) at a color temperature of 5600 K to avoid yellow tints.

The camera used was a Canon EOS Rebel T7 (digital DSLR) with an EF-S 18-55mm IS II Kit lens. A 55 mm focal length and a 13 in. distance from the sensor plane to the container the was used to see details of the droplets forming while also seeing how the droplets changed as they dropped. A 30 frame per second frame rate was used, which was also the video play back speed, so the video is plated in real time. The camera has a video resolution of 1920 x 1080 pixels, but 150 pixels were cropped on each side to remove areas of the background that had different levels of light and less flow activity (Fig. 1a-b). This crop made the final video resolution 1620 x 1080 pixels. An aperture of f/5.6 allowed a moderate depth of field to keep the droplets in focus, but blurring the background. To achieve proper exposure without clipping highlights or shadows, the ISO was set to 400. The shot was composed to fill the frame with flow elements, while being able to see just above the water surface to see when, and to see the details of the droplet falling as well as reflection thereof on the bottom of the water surface. Edits were made in DaVinci Resolve, including included increasing saturation for the dyed detergent, and increasing the brightness of the background for more contrast (Fig. 1a-b). The spatial resolution is such that the thin strands particles are represented by a few pixels. given the resolution of 1920 x 1080 pixels, the spatial resolution is between 2 to 3 orders of magnitude. This resolution is sufficient for this laminar flow where there are not many small scale flow phenomenon occurring.

Conclusion

The video reveals the interactions of water and detergent, and how surface tension, viscosity, and density interplay, fulfilling the intent of the visualization. This precise phenomenon has not been documented before, to my knowledge. I like the choreography of the video with droplets added quickly, showing multiple stages of the process simultaneously, creating many long, thin fingers. I wish that I could also include smaller details of the flow, but this may require a macro lens. The phenomenon could also be turned into a still photo, after adding droplets from left to right sequentially, so maybe 5 or so different stages could be seen in one photo.

References:

De Kruijf, M.; Slootman, A.; De Boer, R. A.; Reijmer, J. J. G. On the Settling of Marine Carbonate Grains: Review and Challenges. *Earth-Science Reviews* **2021**, *217*, 103532. https://doi.org/10.1016/j.earscirev.2021.103532.

Procter & Gamble. Material Safety Data Sheet: Tide Liquid Laundry Detergent. https://www.aoc.nrao.edu/engineering/ElChemInventory/Merged%20Files%20BC2/Tide.pdf

Sutherland, D. N.; Tan, C. T. Sedimentation of a Porous Sphere. *Chemical Engineering Science* **1970**, *25*, 1948–1950. https://doi.org/10.1016/0009-2509(70)87013-0.

Tanaka, M.; Girard, G.; Davis, R.; Peuto, A.; Bignell, N. Recommended Table for the Density of Water between 0 C and 40 C Based on Recent Experimental Reports. *Metrologia* **2001**, *38* (4), 301–309. https://doi.org/10.1088/0026-1394/38/4/3.