CU Boulder

Team Third Report

MCEN 5151-002

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11-21-2025

Introduction

This intent of the short video visual to capture and analyze a simple yet physically rich interfacial flow phenomenon driven by surface tension gradients. After several trials attempting more complex household flow demonstrations, the final image focuses on the well-known pepper and soap interaction. The objective was to document the Marangoni effect in a controlled manner and produce a high-contrast visualization highlighting how the pepper particulates rapidly migrate away from the region where dish soap was introduced.

Context and Purpose

The apparatus consisted of a white ceramic bowl approximately 12 inches in diameter filled almost completely with tap water. A uniform sprinkling of ground black pepper formed a floating particulate layer on the free surface, with particle sizes ranging from roughly 0.3 to 1 mm. Dish soap was applied using the tip of a plastic dropper to ensure a controlled, point-source introduction at the center of the field of view. A still from the video is shown in Figure 1 below.

The physics is dominated by the Marangoni effect. When soap is introduced, it locally lowers the surface tension of the water. Surface tension gradients create tangential stresses along the interface, producing an outward radial flow away from the contaminated region. The pepper flakes act as passive tracers, responding to this rapid surface acceleration. The motion is primarily two-dimensional and occurs within the first few millimeters of the free surface, where the surface tension forces dominate over viscous forces. This produces an impulsive burst of outward motion followed by a slower decay as the surface tension gradient dissipates.

A Reynolds number estimate characterizes the flow regime. Taking a characteristic velocity of $U \approx 0.3\ \mathrm{m}/s$based on frame-by-frame video analysis and a characteristic length of $D = 0.10\ \mathrm{m}$(half the bowl diameter), and the kinematic viscosity of water $\nu = 1.0 \times 10^{-6}\ \mathrm{m}^2/s$,

$$Re = \frac{UD}{\nu} = \frac{(0.3)(0.10)}{1.0 \times 10^{-6}} = 3.0 \times 10^4.$$

This Reynolds number indicates an inertially dominated, highly unsteady surface flow. The high apparent speed is consistent with published analyses of surfactant-driven Marangoni spreading, which show that surface tension gradients can generate strong radial accelerations before the system relaxes (Jensen, 1995; Matar & Troian, 1999). Because the flow is transient and primarily constrained to the interface, the bulk water remains nearly stagnant while the pepper layer rapidly reorganizes.

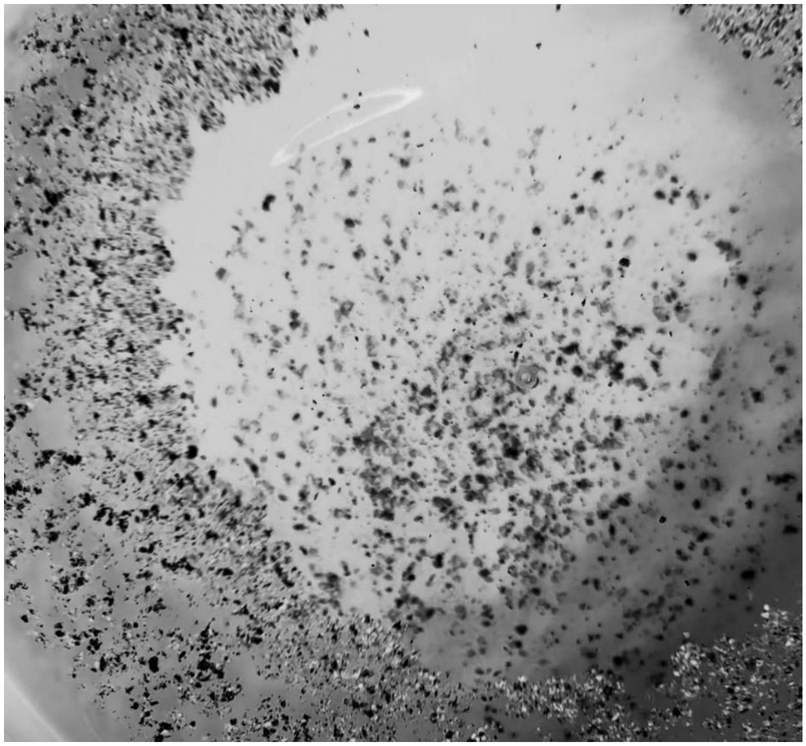

Figure 1. Still Image

Visualization Technique

The primary visualization agent in this setup was the ground black pepper, used as a passive tracer floating on the free surface due to its hydrophobicity and low density. The pepper was generic store-brand black pepper, medium grind. The water was room-temperature tap water, and the dish soap was Dawn Original Ultra detergent, chosen because surfactants in household soaps produce strong surface tension gradients that clearly reveal Marangoni stresses.

Lighting was provided by ambient indoor LED illumination supplemented by the phone's screen light reflected from above to reduce shadows. The bowl's white ceramic surface acted as an effective diffuser, creating even, soft lighting across the field of view. No external flash or specialized lighting equipment was used. The lighting goal was to maximize contrast between the dark pepper particles and the bright background to emphasize their rapid displacement.

Photographic Technique

The image was captured using an iPhone 14 Pro Max in video mode at 30 frames per second, then exported as a still frame. The original resolution was 2796 × 1290 pixels. The phone was positioned approximately 5 inches above the bowl in a fixed overhead orientation.

Exposure was controlled automatically by the device. The resulting values provided a bright, noise-free image while maintaining enough depth of field for the entire water surface to remain in focus. Post-processing was limited to conversion to grayscale and modest contrast enhancement to increase the visibility of particle clustering. The cropping was adjusted to center the region where the pepper migrated outward.

Conclusion

The final image reveals the sharp boundary created as the pepper rapidly evacuates the central region due to strong Marangoni stresses. The radial distribution of particles traces the decaying motion, and the high contrast helps make the transient pattern visually compelling. The image successfully captures the moment immediately after the soap contacts the water and the texture of the particle field helps illustrate the nature of the flow.

One limitation is the slight nonuniform illumination near the upper portion of the image, where reflections introduce a bright patch. A more controlled lighting environment or the use of matte surfaces around the bowl would reduce glare. Future iterations could also use higher-speed video to better quantify the particle velocities and compute surface flow gradients. Additionally, colored surfactants or fluorescent tracers could enhance the visualization of the spreading front. Overall, the intent of highlighting surface-tension-driven flow was fully achieved, and the experiment demonstrated how a simple household setup can reveal complex interfacial fluid dynamics.

References

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4. University of Illinois Physics Van. “Why does pepper run away from dish soap?” https://van.physics.illinois.edu