CU Boulder

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MCEN 5151-002

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Introduction

This image was created as part of a flow visualization study to capture the interaction between a surfactant-laden liquid and an impinging water jet. A thin layer of blue dish soap was placed in a stainless-steel sink and water was introduced from a tap, generating entrained air, bubbles, and surface flow structures. The final composition was intentionally cropped to emphasize regions of high visual and physical interest, where bubbles of varying sizes are stabilized by the presence of surfactants. These features reveal localized gradients in surface tension, variations in viscosity, and shear-driven instabilities at the liquid–air interface. The purpose of the visualization is both artistic and scientific, simultaneously highlighting the aesthetic qualities of the patterned bubble fields while providing insight into the fluid mechanics of bubble formation, surfactant stabilization, and surface-tension-driven flows.

Context and Purpose

The flow visualization was performed in a standard stainless-steel sink basin (approx. 0.4 m × 0.4 m in plan), with a pool of blue Dawn dish soap spread across the base surface. Water was introduced via a vertical tap stream falling from a height of about 1 ft (≈ 0.30 m) above the soap-covered sink floor. The impinging jet diameter at the orifice was approximately $D = 5$mm, and the tap pressure and plumbing configuration delivered a flow velocity estimated on the order of $U = 0.3$to 0.6m/s at the point of impact (based on volumetric flow and nozzle cross section). The high level details of this set-up are shown in Figure 1.

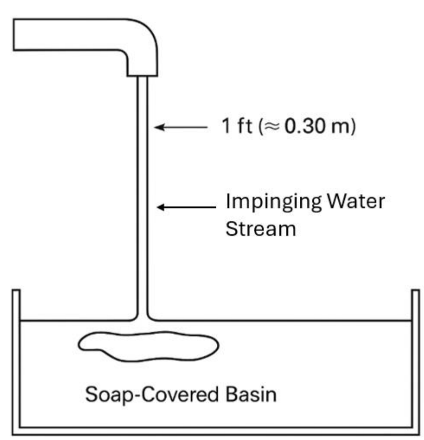

Figure 1. Flow Visualization Set-Up

Upon impact, the jet entrains air and generates a region of high local shear and interface deformation, leading to bubble nucleation and interfacial flows.

To characterize the flow regime, a Reynolds number based on the jet diameter can be estimated. Taking $U = 0.5$m/s, $D = 0.005$m, and using the kinematic viscosity of water $\nu = 1.0 \times 10^{-6}$m^2/s,

$$Re = \frac{UD}{\nu} = \frac{(0.5\ \mathrm{m/s})(0.005\ \mathrm{m})}{1.0 \times 10^{-6}\ \mathrm{m^2/s}} = 2500.$$

A Reynolds number of about 2,500 suggests the jet is in the transitional regime, with the potential for both laminar-like and incipient turbulent behavior near the impact zone. In this regime, inertial forces begin to dominate over viscous ones, but viscous dissipation and interfacial phenomena remain significant in shaping bubble formation and interface motion.

Another useful nondimensional parameter is the Weber number, comparing inertial to surface tension forces:

$$We = \frac{\rho U^2 D}{\sigma},$$

where $\rho = 1000$kg/m^3 (water density) and $\sigma$is an effective surface tension of the soap-water mixture. Assuming $\sigma \approx 0.03$N/m (a rough estimate for surfactant-laden water),

$$We = \frac{(1000)(0.5^2)(0.005)}{0.03} \approx 41.7.$$

A Weber number on that order implies that inertial forces are sufficient to deform interfaces and generate bubbles, but surface tension is still crucial in resisting breakup and governing bubble stabilization.

Because of the presence of surfactant molecules from the dish soap, the interface exhibits nonuniform surface tension due to concentration gradients. Marangoni stresses act to oppose local thinning or stretching of the interface, thereby stabilizing small bubbles and suppressing rapid coalescence. The surfactant-laden interface effectively "rigidifies" relative to a clean interface, slowing interface deformation and drainage. This interfacial "immobilization" effect has been observed in many surfactant bubble and drop studies [1] has been shown to delay bubble-bursting and merger kinetics [2] on surfactant influence on drop production by bubble bursting.

In this experiment, the competing interplay of inertial forcing, viscous dissipation, capillarity, and Marangoni stresses yields a quasi-steady yet spatially evolving bubble field.

Visualization Technique

The visualization was achieved by spreading the dish soap across the sink basin. The soap served as both a reflective surface and an active surfactant that modified bubble formation, allowing the bubble-laden regions and radial flow patterns to be captured clearly. Tap water from the faucet was the sole fluid source, with no additional dilution of the soap film required beyond a uniform thin coating applied manually across the sink base.

Illumination was provided by a consumer-grade LED overhead fixture supplemented by the camera's built-in flash. The flash was oriented perpendicular to the flow axis, creating specular highlights on the soap film and bubbles, which enhanced the visibility of interfacial deformations and gradients in bubble density. The combination of the soap's natural reflectivity and the direct flash lighting yielded sufficient contrast to resolve both the stagnation region and the radial spreading flow in the captured images. The described materials and lighting conditions can be replicated easily in a standard sink environment with similar dish soap and a digital camera equipped with flash.

Photographic Technique

The photographic capture was performed using a Canon EOS Rebel T3i DSLR camera equipped with a Canon EF-S 18–55 mm f/3.5–5.6 (model 2042B002-cr) zoom lens. The camera was positioned about 0.6 m above the sink, oriented directly along the axis of the falling jet to capture the stagnation region and radial spreading flow.

Because the camera was operated in automatic exposure mode, aperture, shutter speed, and ISO values were selected by the camera software to optimize exposure under the available room lighting and built-in flash. Settings for this configuration (recorded in image metadata) were an aperture value of f/4, 1/60 s shutter speed, and ISO 400, and the final size was 1920 x 1280. The built-in flash provided additional illumination to highlight bubble surfaces and reflections on the soap film.

Image processing was limited to cropping and modest global adjustments in brightness and contrast to improve clarity of the bubble field. No local editing or digital retouching was performed, ensuring that the final image accurately represents the observed flow features. The original photo is shown in Figure 2 below.

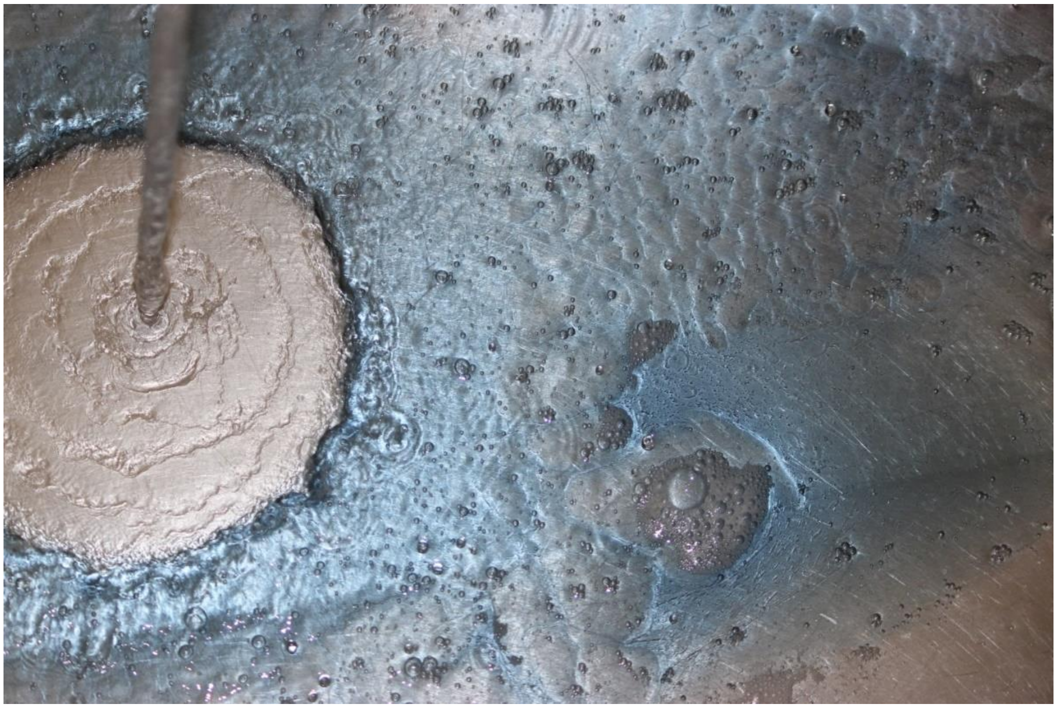

Figure 2. Original Image

Conclusion

The image captures a surprisingly detailed view of the soap film and bubbles created by the impinging water jet. What stands out most is the way the texture of the surface. The light reflects off the blue film and makes the bubbles shimmer, almost like tiny jewels, and highlights the swirling patterns left behind by the flow.

One thing that could use work is showing the larger context or the radial spreading. Instead, it is zoomed in on just one region of the flow. While this reveals beautiful details, it does not fully communicate the bigger picture of how the water jet and soap film interact. Still, the image does a good job of showing the delicate balance between order and randomness in fluid motion.

Looking at the image raises new questions: how do the bubbles decide where to cluster? Why do some stay small while others grow and merge? Improvements could include experimenting with wider shots to show more of the flow structure or using high-speed video to reveal the fast changes happening between frames. However, this image ultimately met its intent of capturing the dynamics of flow in an artistic yet physically meaningful way.

References

1. Pierre, J., Poujol, M., & Séon, T. (2022). Influence of surfactant concentration on drop production by bubble bursting. *Physical Review Fluids, 7*(7), 073602. https://doi.org/10.1103/PhysRevFluids.7.073602
2. Tagawa, Y., Takagi, S., & Matsumoto, Y. (2014). Surfactant effect on path instability of a rising bubble. *Journal of Fluid Mechanics, 738*, 124–142. https://doi.org/10.1017/jfm.2013.588