Team Second Report

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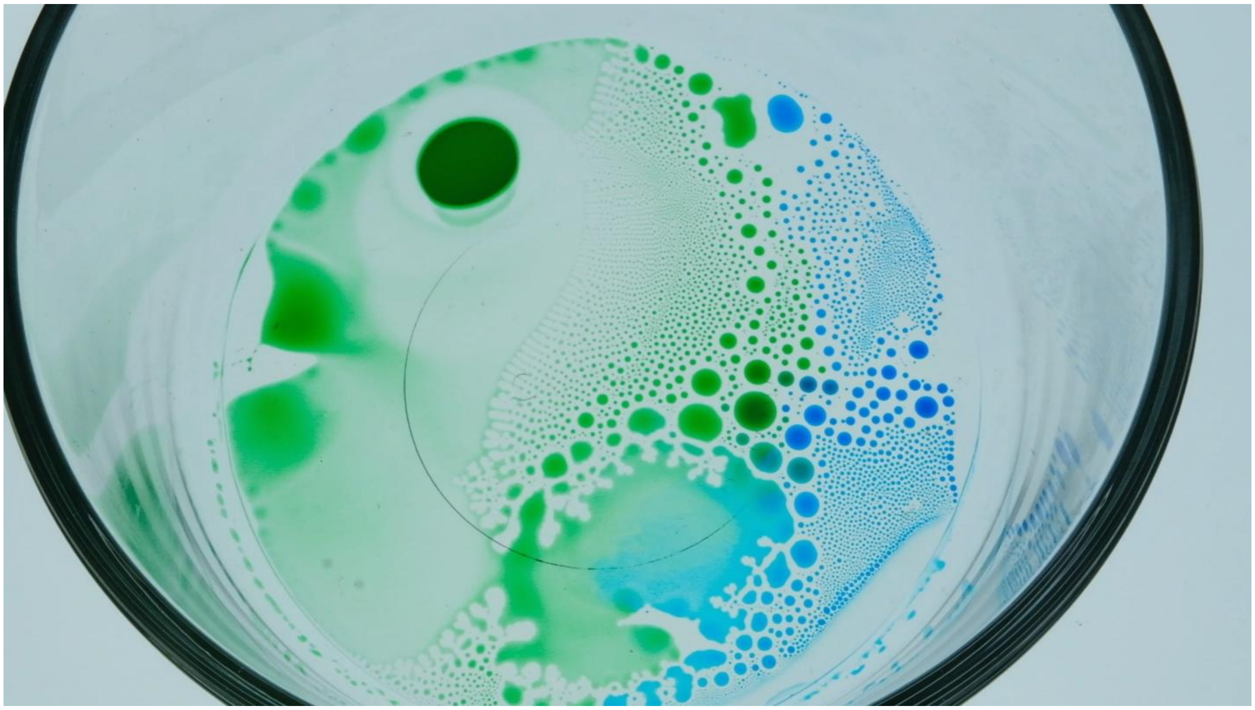
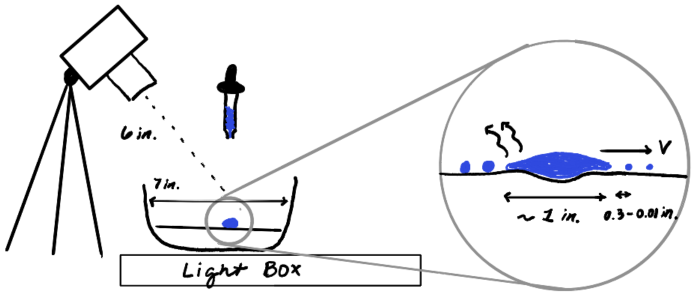


1. Introduction

For this project, I wanted to capture a dynamic and surprising example of Marangoni flow, focusing on the moment when an alcohol droplet suddenly collapses and breaks apart into many smaller droplets. The behavior is visually striking. The droplet first spreads smoothly and looks calm, then the rim snaps inward and fragments into a collection of much smaller drops. I was curious about how the alcohol-to-water ratio might change the timing and size of the breakup, so part of this project was experimental exploration. Overall, my goal was to highlight the instability clearly and show the wide range of scales, from the large “mother” droplet to the tiny daughter droplets that form at the end.

2. Setup

The experiment used a shallow glass dish filled with a 2 to 3 millimeter layer of cooking oil. The droplet mixture was 8 milliliters of 70 percent isopropyl alcohol, 2 milliliters of water, and 6 to 8 drops of food dye. I placed droplets on the oil surface using a pipette. Because alcohol evaporates quickly, the exact mixture can shift slightly over time.



When the droplet first contacts the oil, its lower surface tension pulls fluid outward. This is a solutal Marangoni effect. As alcohol evaporates, evaporation is strongest at the rim, so surface tension increases there first [1]. Once the rim becomes water-rich, the surface tension gradient reverses and the interface retracts inward. This rapid inward pull causes the droplet to collapse and eject smaller droplets. Similar bursting behavior has been documented in recent studies [1][2].

The Reynolds number characterizes the ratio of inertial to viscous forces in the flow:

$$Re = \frac{\rho U L}{\mu}$$

For this experiment, the relevant viscosity is that of the underlying oil layer, since the droplets shear the oil surface as they move:

- Fluid density: $\rho = 1000$ kg/m^3
- Characteristic velocity: $U = 0.02$ m/s
- Characteristic length scale (droplet diameter): $L = 3 \times 10^{-3}$ m
- Dynamic viscosity of vegetable oil: $\mu = 0.05$ Pa·s

Substituting:

$$Re = \frac{(1000)(0.02)(3 \times 10^{-3})}{0.05}$$

$$\boxed{Re \approx 1}$$

This suggests laminar, surface-tension-dominated flow. The Marangoni number for alcohol concentration gradients in similar systems is typically on the order of $10^3$to 10^4[1], which is consistent with the rapid motion that overcomes viscous damping.

3. Visualization Technique

To highlight the flow and breakup, I used food dye mixed into the alcohol. Two colors were used to reveal mixing and separation. The dish was placed on an artist's tracing pad, which provided bright and even lighting from below. This lighting setup increased contrast and avoided glare and reflections that would have occurred with front lighting. The camera was positioned approximately six inches above the dish on a small tripod.

4. Photographic Technique

Although still images of this phenomenon are fantastic, I wanted a video to capture the dynamic behavior. Given that the lighting was nearly optimal, a range of camera settings would have worked here. I opted for a medium aperture in order to extend the depth of field, and then adjusted ISO to get the correct exposure. The smallest resolvable feature in this flow is a tiny droplet only 2-3 pixels wide, which corresponds to about 0.01 inches.

Camera	Fujifilm X-E4
Focal Length	58 mm
Aperture	f/8
ISO	2000
Shutter Speed	1/30 s
Resolution	1920 x 1080 pixels
FOV	6.5 x 5 inches

I edited the video in DaVinci Resolve. The first part of the clip is sped up by a factor of 10 to show the gradual spreading phase. As the collapse begins, the video returns to real-time playback so the burst and tendril formation are easier to see.

5. Conclusion

For me, the final visual is a huge success. In the beginning you can see the beautiful Marangoni flow, with lots of droplets dispersed and flow stagnating at the boundaries between mother droplets. Then as the alcohol evaporates, the mother droplets rapidly collapse, forming tendrils due to momentum. The physics are well resolved in space and time. My only regret is that there is some color noise caused by too high of an ISO. Furthermore, if I were to repeat this experiment, I would improve how I used the dye. Better matching alcohol ratios between the two colors and dropping the same amount of alcohol would reduce the asymmetries present in my visual.

6. References

[1] M. Ślemp and A. Miniewicz, “Marangoni bursting: Insight into the role of the thermocapillary effect in an oil bath,” Fluids, vol. 8, no. 9, p. 255, 2023, doi: 10.3390/fluids8090255.

[2] A. Hooshanginejad and S. Jung, “Buoyancy-Marangoni fingering of a miscible spreading drop,” Symmetry, vol. 14, no. 2, p. 425, 2022, doi: 10.3390/sym14020425.