"Get Wet" Report: Interacting Marangoni Bursts

MCEN 5151-001 Flow Visualization, Fall 2025
Emma Wilder, 9/18/2025

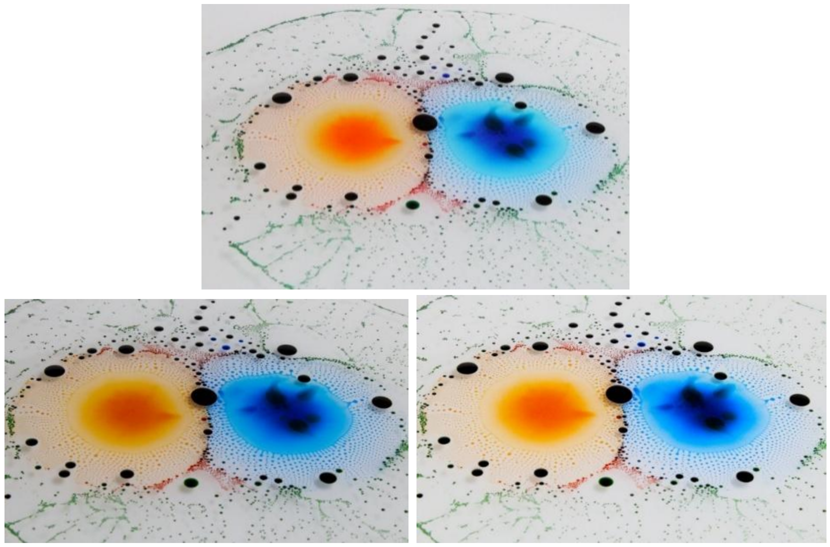

Fig. 1: The project image: (A, top) unedited image (B, bottom left) original edited image submitted and (C, bottom right) re-exported edited image

Figure 1 was created to capture the interaction of multiple Marangoni bursts with various colors. I first saw a video capturing Marangoni bursting (Durey et al., 2018) and was fascinated by a drop bursting into thousands of tiny droplets in a beautiful and symmetrical way. A drop of isopropyl alcohol (IPA) mixed with water and dye was placed on a layer of oil to create this effect that demonstrates the effect of a surface tension gradient. This video was based on a paper by Keiser et al. (2017) which demonstrated how the phenomenon is impacted by various concentrations of IPA and initial drop size. The accompanying video was beautiful, but I saw the opportunity to capture the beauty of this phenomenon in a different way. The video I saw used one color of droplet, with a vertical orientation, and they only used one drop at a time. By using multiple droplets of different colors and taking a still image, a different perspective and beautiful image could be captured.

The setup used a circular white bowl filled with Crisco Pure Vegetable Oil to around 0.5–1.0 cm depth (Fig. 2a). The colored drop ("mixture") was made by mixing water, IPA, and food dye. The IPA used (Kroger First Aid Antiseptic Isopropyl Alcohol) was 70% concentration by volume; 5 mL of this IPA was mixed with 1.25 mL of tap water with 20 drops of food coloring (Kroger Food Colors, Assorted Colors), to achieve around 40–50% IPA by mass, which was over the critical concentration of 35% to observe this phenomenon (Keiser et al., 2017). The image was captured around 15–20 seconds after the drops were initially added.

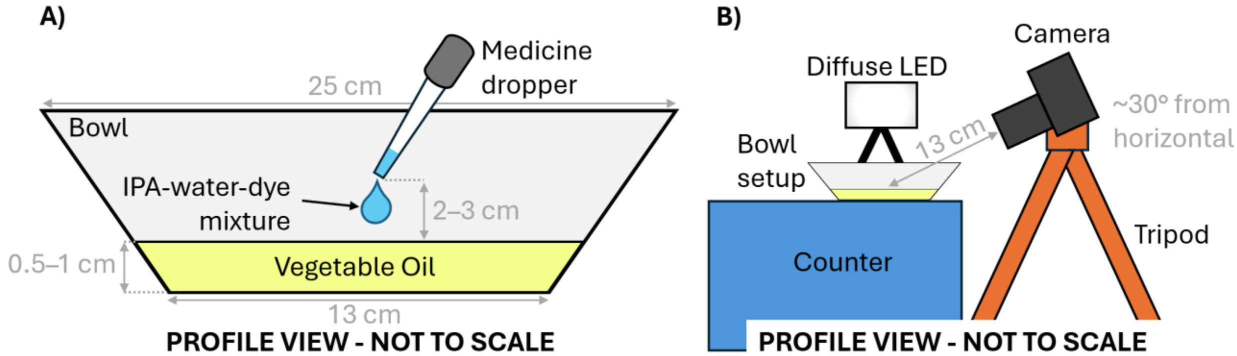

Fig. 2: Profiles of experimental setup including (A) a close up of bowl, and (B) entire shooting setup with camera and lighting

The phenomenon of Marangoni Bursting relies on a gradient of surface tension (Scriven and Sterling, 1960; Keiser et al., 2017). When first placed on the vegetable oil, the mixture sits on top of the oil, and it is deeper in the center than on the edge. IPA evaporates rapidly at room temperature at a rate of around 0.1 mm/s (Keiser et al., 2017), which is significant at the thinner edges. Therefore, the edges of the mixture mother droplet (Fig. 3) become depleted of IPA, leading to a gradient of IPA concentration from the center to the edge. Water has a higher surface tension (γ) than IPA due to hydrogen bonding between water molecules, so this concentration gradient is also a surface tension gradient. Since there is a higher concentration of water along the rim of the mixture, it leads to a higher surface tension along the outside of the mixture. The surface tension gradient leads to an imbalance of intermolecular forces with net force on the mixture mother droplet pointing outwards (Fig. 3), making the mixture flow towards the edge and thus making the edge expand. When the edge of the mother droplet can no longer expand, fingers form that transform into circular droplets due to surface tension (Fig. 3), somewhat resembling Plateau–Rayleigh instability (Keiser et al., 2017), but this scenario is different because the orientation of the fingering is not vertical and it is sitting on a layer of oil. These circular droplets have some kinetic energy from the surface tension gradient, but this energy is dissipated in the viscous oil, leaving distinct outer ring with many droplets that have become tiny and intensely colored from evaporation of the remaining IPA. The intention behind the image was to capture the interaction of multiple Marangoni bursts, which displays the forces from a surface tension gradient pushing against each other. Therefore, the interface between the blue and yellow bursts approaches a straight line and does not allow the burst to extend as far as on the far sides: the forces are opposing each other here. At some places along the interface, the droplets re-form into larger droplets because the force is large enough to overcome the surface tension in the smaller droplets. This process forms the larger darker droplets because of the mixing of multiple dyes which are at a high concentration due to evaporation of IPA. Remnants of previous green and red bursts surround the blue and yellow bursts for artistic effect and to show the spreading of the droplets due to the force of the surface tension gradient.

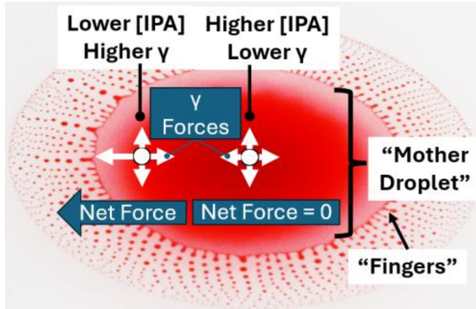

Fig. 3: Diagram of Marangoni Burst and surface tension forces present causing an outwards flow for particles towards the edge and bursting of this edge.

Keiser et al. (2017) found that the wavelength of fingers (Fig. 3) is impacted by the initial IPA concentration. The wavelength between fingers observed in Fig. 1 is estimated using the scale and the number of fingers. The blue mother droplet has approximately 80 fingers (Fig 1c). Assuming the diameter of the blue mother droplet is around 2.5 cm based on image scaling, the finger wavelength is approximately 1.0 mm, which aligns with the results in Keiser et al., (2017) for 40% IPA (error bar shown as approximately 0.7–1.3 mm). Nondimensional numbers such as the Reynolds number are not applicable to this phenomenon, although a characteristic radius ($R*$) was used in Keiser et al., (2017) to estimate the maximum radius (R_{max}) using a regression. $R*$ is calculated with Eq. 1 below using initial and critical IPA mass concentrations (φ_0 & φ_c), drop volume (Ω_0), difference in surface tension ($\Delta\gamma$), depth of oil (H), oil viscosity (η_0), and IPA evaporation rate (j_v). Using appropriate values from this experiment and other values used in Keiser et al., 2017, $R*$ can be calculated as 61 mm. Using the regression in Keiser et al., 2017, the maximum mother droplet radius can be estimated at 18 mm, which is similar to the maximum observed radius of around 25 mm.

$$R^* = \left(\frac{(\Phi_0 - \Phi_c)\Delta\gamma H\Omega_0}{(1-\Phi_c)\eta_0 j_v}\right)^{1/4} \qquad \text{Equation 1}$$

$$R^* = \left(\frac{(0.4-0.35)\left(\frac{0.001\,N}{m}\right)(0.005\,m)(2*10^{-7}\,m^3)}{(1-0.35)(0.055\,Pa*s)(10^{-7}\,m/s)}\right)^{\frac{1}{4}} = 61\,mm \rightarrow R_{max} \approx 18\,mm$$

The visualization technique included the addition of food coloring to the water-IPA mixture, which contrasted from the white bowl beneath the transparent oil (i.e., marked boundary technique). The lighting included a nine-inch diffuse LED light panel (NEEWER). This panel was directed towards the bowl downwards at about a 45° angle, with the center of the light around 12 cm from the center of the bowl. A color temperature of 5000 K was used to avoid highlighting the oil's yellow tint. The maximum 100% intensity was used to allow enough light for the larger depth of field required for the angled shot.

The photographic technique considered novelty and artistic elements. An angled shot (30° from horizontal, Fig. 2b) was desired to change the perspective from the commonly captured vertical angle orthogonal to the plane of the oil surface. Although some blurring was desired at the very top and bottom of the image for some perspective and aesthetics, it was desired to retain most of the image in focus. Therefore, a larger depth of field than could be achieved by a f/5.6 aperture (the widest aperture at the 55 mm focal length) was needed. To maintain most of the image in the field of view, and aperture of f/32.0 was used. To keep the shutter speed high enough to prevent motion blurring (1/30 s), an ISO of 3200 was needed for proper exposure. Since the droplets were moving approximately 0.25 cm/s, which is around 2.5% of the field of view per second, a shutter speed of 1/30 s means that the flow would move less than 0.1% of the image over the exposure time, which is adequate to capture the flow detail. This choice resulted in some noise in the image, but also arguably adds to the character and aesthetic effect and separates it from existing imagery that has a very high brightness and low noise. A 55 mm focal length was used to see detail with a distance of the lens of about 13 cm from the center of the bowl (Fig. 2b). The digital DSLR camera used was a Canon EOS Rebel T7 with an EF-S 18-55mm IS II Kit lens. This camera takes an image that is 6000 x 4000 pixels (Fig. 1a) but was cropped down to 5425 x 3272 pixels to have the droplets fully fill the frame and maintain some of the droplets from previous bursts. Image processing in darktable involved increasing contrast by implementing an s-curve in the RGB curve and increasing saturation to bring out the color of the droplets. However, when first exported and submitted, some of the color and contrast edits did not appear to get applied (Fig. 1b), but they were then re-exported (Fig. 1c). The width of the image is around 10 cm in the center but is variable due to the angle of the shot (Fig. 2b).

The image reveals the phenomenon of Marangoni Bursting and how the forces of multiple bursts interact with each other. I artistically like that the image has multiple colors from previous bursts and shows the larger darker droplets from multiple colored droplets mixing together. It is also interesting that the surface tension differential was enough to overcome the surface tension of the smaller droplets to do this. From a scientific perspective, the other color droplets could be viewed as distracting, and the noise from the high ISO needed to achieve the high depth of field for the angled shot could be distracting. I could develop this idea further by testing different combinations of IPA concentration and seeing if the differences surface tension forces are visible at the interface between droplets (i.e., if a droplet with higher initial IPA concentration has a higher surface tension that will push more strongly against a droplet with lower initial IPA concentration and have a convex shape at its interface instead of concave). I could try this without having dye from previous bursts present, with a controlled volume of droplets at the precise time to produce an image more directly useful for a scientific publication. This could also be improved by making it into a video to show the progression of the flow.

References:

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