Get Wet Report

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Flow Visualization – Section 5151

No Assistance

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While thinking of concepts for this assignment, I was immediately drawn to the idea of trying to curdle milk. This idea came from memories of trying to make cheese years ago, and the interesting flows I remember seeing. I took a quick trip to the store for some lime juice and immediately began mixing milk and the acid. Although the curdling was immediate, I realized it would be somewhat tricky to try to get a good visual due to the relative opacity of the milk.

The milk was held in the concave underside of a wineglass. The dish formed a reservoir approximately 2.5 in (63.5 mm) in diameter and 0.25 in (6.35 mm) deep (Figure 3). Milk was poured in until approximately flush with the rim all the way around. A shot glass was then used to release a few drops of dyed lime juice at the center. The pattern visible in the image is produced by the following chemical reaction: citric acid from the lime juice lowers the pH of the milk, causing the casein micelles to curdle where the acid reached (The Kitchn, 2019; Burma, 2019). This resulted in a roughly circular curdled region that grew outward from the center. As the acid spread from the center, the curdled section became more translucent, allowing more light through and highlighting the structures that had formed.

Approximately 10 s after the drop when the photo was taken the curdled region had expanded to approximately 1.25 in (31.8 mm) in diameter. The radius of the curdle section was roughly 0.625 in (15.9 mm). This gave an average speed of $U \approx 15.9\,\mathrm{mm}/10\,\mathrm{s} \approx 1.6 \times 10^{-3}\,\mathrm{m\,s^{-1}}$.

Treating the depth of the milk layer, $h \approx 6.35 \times 10^{-3}\,\mathrm{m}$, as the relevant length scale, and taking the kinematic viscosity of whole milk as $\nu \approx 1.7 \times 10^{-6}\,\mathrm{m^2\,s^{-1}}$ (based on a reported dynamic viscosity of 1.75 cP at 20 °C and a density of $1030\,\mathrm{kg\,m^{-3}}$) (Bakshi & Smith, 1984), the Reynolds number for the spreading front is:

$$Re = \frac{Uh}{\nu} = \frac{\left(1.6 \times 10^{-3}\ \mathrm{m\,s^{-1}}\right)\left(6.35 \times 10^{-3}\ \mathrm{m}\right)}{1.7 \times 10^{-6}\ \mathrm{m^2\,s^{-1}}} \approx 6 \tag{1}$$

A Reynolds number this small seems to mean that the flow is almost entirely dominated by viscosity rather than inertia. Which would mean that the front advances smoothly rather than mixing turbulently. This does seem to be reflected in the flows that I had observed, with very smooth edges and no super sharp edges.

To get around the opacity issue, I realized I would have to get creative about the lighting and setup. What I eventually realized was that if I wanted to get good contrast between the milk and the curdles, it was advantageous to perform the "reaction" in a thin layer.

Two separate sources of contrast were used to make the flow visible. First, I dyed the lime juice with a small amount of green food coloring. Second, the curdling itself provides contrast. As described above curdled milk becomes more translucent than the surrounding uncurled milk, and due to the backlight the curdled areas appeared brighter. The lime juice was dripped into the center of the milk rather than being stirred in, so the reaction spread outward on its own. Lighting was provided by a flashlight aimed up through the stem of the inverted wine glass. This added backlight to the thin milk layer from directly below which made the curdled regions stand out.

The final photo was taken on an iPhone 17 Pro Max, using the rear ultra-wide camera (2.22 mm focal length, 24 mm 35 mm-equivalent, f/2.2). Exposure was 1/60 s shutter speed, f/2.2 aperture, and ISO 400. The image was processed in darktable where I cropped the photo into a square, boosted the contrast slightly to highlight the structures formed, and added a circular vignette to match the circular rim of the wineglass. The final image size was 2093×2450 pixels. The before version of the image is shown in Figure 2 for comparison.

I think the contrast between the normal milk and the curdling milk came out super clear which I am very happy about. I also love how clear the curdling structures are visible, it really shows what I was hoping to convey. I would love to see this phenomenon under a microscope, or maybe a much more focused photo. Next I would like to try a much stronger acid, I think it would curdle more "explosively" and make for better viewing.

References

The Kitchn. (2019). *Food Science: Why Lemon Makes Milk Curdle*. Retrieved from https://www.thekitchn.com/food-science-why-lemon-makes-m-88057.

Burma, P. (2019). *Curdling of Milk*. Delhi University, hosted via Tata Institute of Fundamental Research. Retrieved from https://www.tifr.res.in/pkjoshi/articles/Curdling-of-milk_030519.pdf.

Bakshi, A. S., & Smith, D. E. (1984). Effect of Fat Content and Temperature on Viscosity in Relation to Pumping Requirements of Fluid Milk Products. *Journal of Dairy Science*, 67(5), 1157–1160.

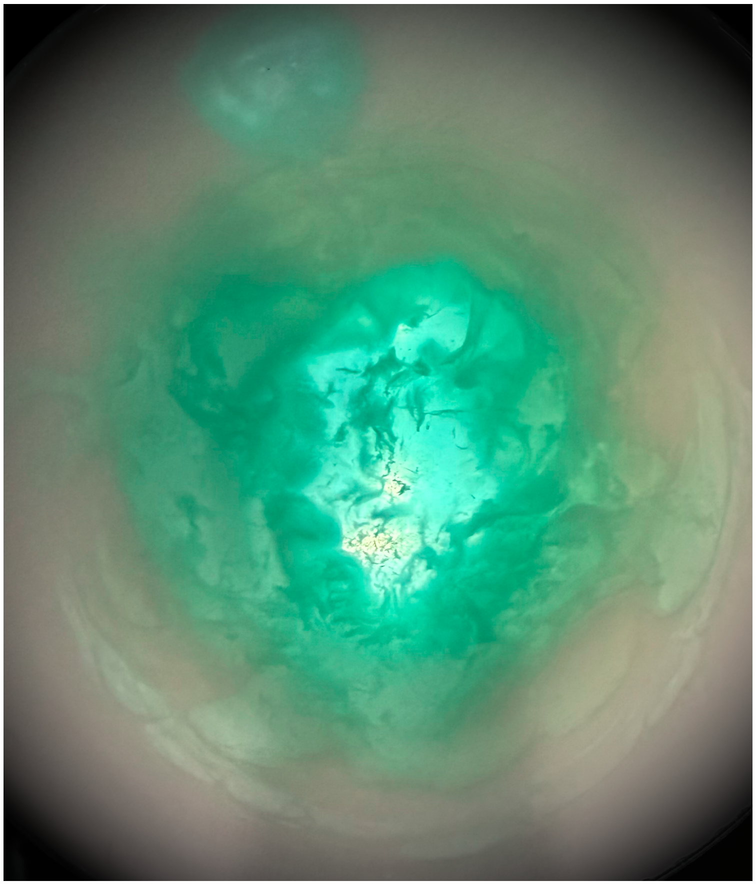

Figure 1: Final edited image.

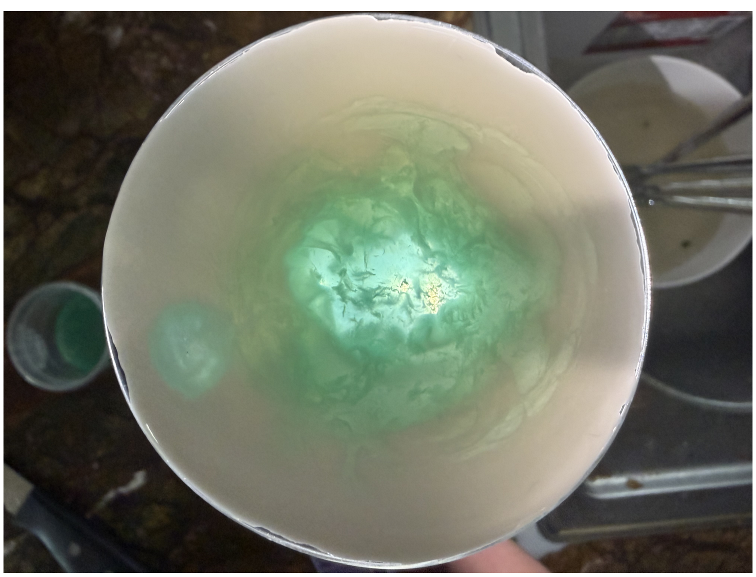

Figure 2: Unedited “before” image, straight from the camera.

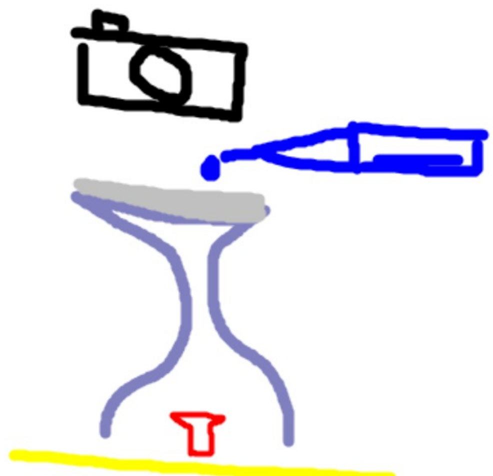

Figure 3: Apparatus sketch: camera above, lime juice dropped from a small glass into the concave base at the top of the inverted wine glass, flashlight lighting from below through the stem.