Team 1: Saffman-Taylor Fingering, *Viscous Lightning*

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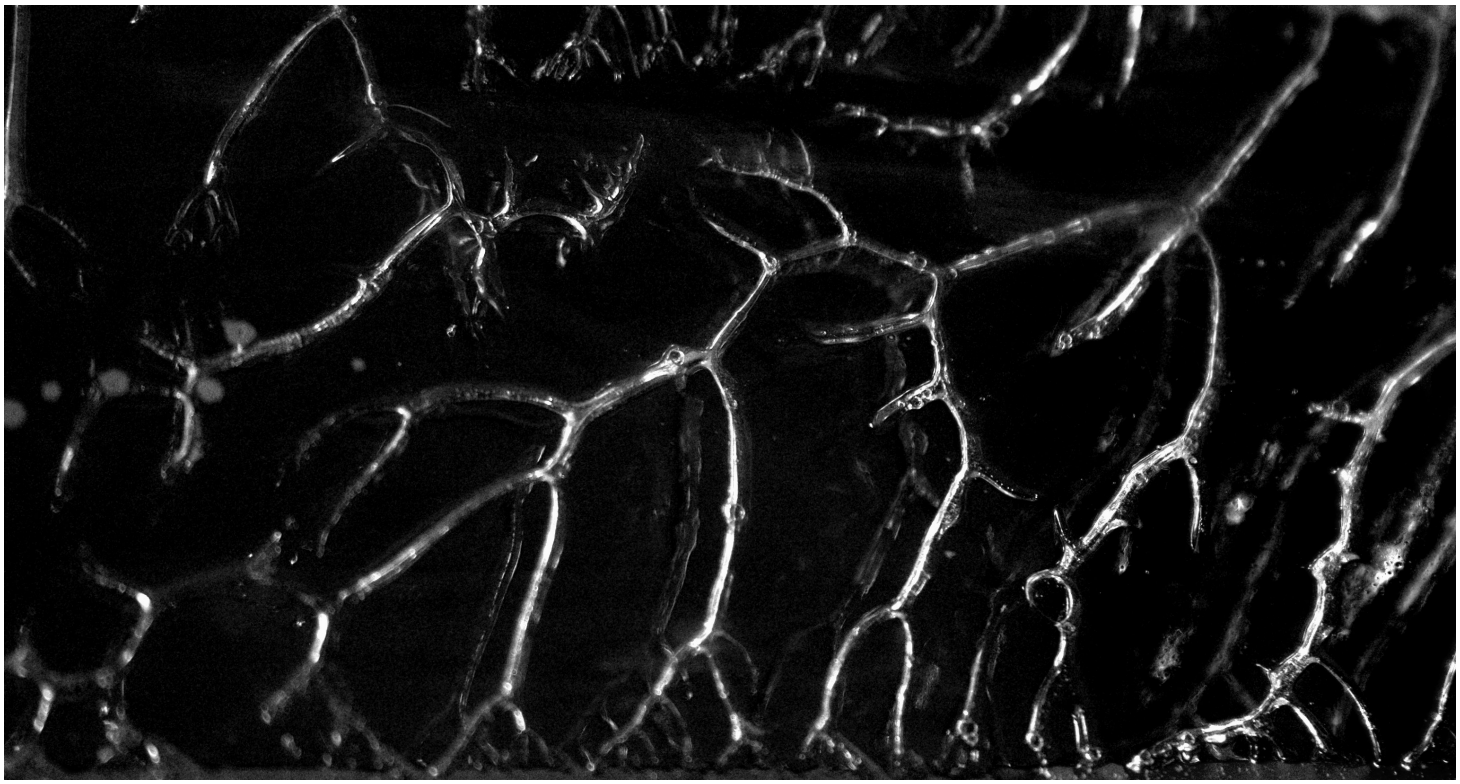

This image, *Viscous Lightning*, was created as a part of the *Team 1* assignment for the University of Colorado MCEN 4151: Flow Visualization course. This was the first team-based assignment of the Spring 2012 semester. The purpose of this assignment is to challenge students to visualize a phenomenon that requires multiple people to set up and capture. During the clean up of another flow visualization project, this phenomenon was observed – the Saffman-Taylor instability. This was then captured in different orientations and lighting, yielding the resulting image.

To create this image, two pieces of acrylic sandwiching a thin layer of shampoo (less than 0.5 mm thickness) were slowly pulled apart. As air entered the region between the plates, a multiphase flow was created as a low-density fluid entered a higher-density fluid. Figure 1 shows the schematic for this visualization. A blue, translucent piece of acrylic (approximately 3 inches wide) had shampoo on it and was covered by a clear piece of acrylic, approximately 5 inches wide. The blue surface was held parallel to the floor. The clear plate was slowly lifted from one side increasing the

angle with respect to the horizontal over time. The amount of shampoo between the plates was enough to hold them together via surface tension but not so much that it was dripping off the sides of the acrylic.

Figure 1: Schematic of visualization setup

The lifting of the upper plate causes a lateral straining flow (Shelley 1997). This means that the low-density fluid (air) is entering the flow and causing the interface of the shampoo to buckle (Shelley 1997). Figure 2 shows the original image. Notice that each junction (where the shampoo interface is buckling) is a triple junction – shampoo "fingers" jut out in a maximum of 3 directions. These patterns were only visible for a few seconds at a time before ultimately collapsing to the point that they were invisible to the naked eye.

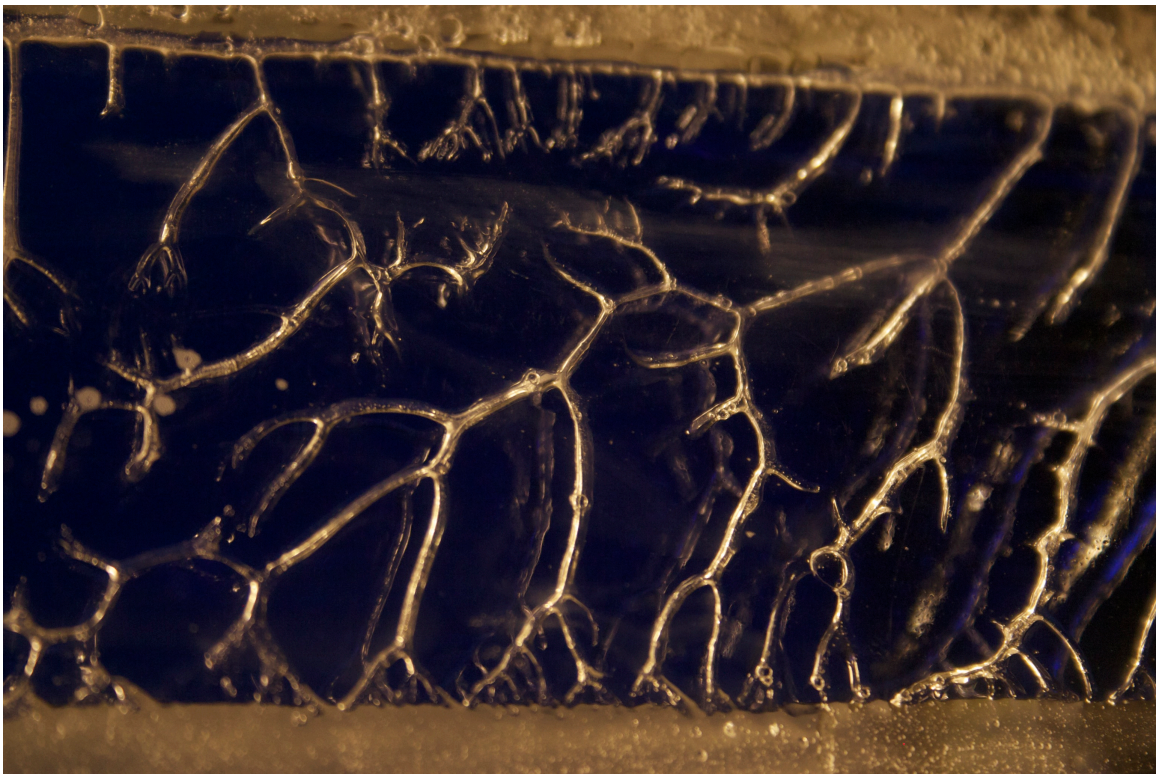

Figure 2: Original image

This instability is known as the Saffman-Taylor instability. Darcy's law can be used to model this flow (Shelly 1997). This is shown in Equation 1 where u = (u,v) is the average velocity of the top clear plate, p is the pressure, $b(t)$ is the gap width with respect to time, and μ is the viscosity. This number will not be computed in this

paper. Darcy's law is used to describe flow behavior through a permeable fluid such as air, seen in this scenario (Darcy 1856)

Equation 1

$$u(x, y, t) = -\frac{b(t)^2}{12\mu}\nabla p(x, y, t)$$

The reason that this phenomenon changes with time is because as the gap widens, the surface tension force is no longer great enough to overcome the gravity forces. After the instability ceased, the remaining shampoo was most commonly on the blue acrylic, which was in the direction of the gravity vector. Direct fluorescent light was from the right side of the setup and this highlighted the instability from only one side. There was no lighting from below. The shampoo was Walgreens generic brand of shampoo for men.

The size of the field of view was approximately 7 inches across. This was the optimal field of view given the proportions of the phenomenon being photographed. The distance from the ice bulbs to the lens was approximately 6 images, optimized to capture as much of the phenomenon as possible while maintaining proximity to the instability. The original image is 6000 x 8000 pixels and was cropped to 3000 x 1000 pixels. The camera was a Canon Digital EOS Rebel. The lens focal length was 55 mm. The exposure settings include an aperture of f/5.6, a shutter speed of 1/640 s and an ISO setting of 800, lending to the particular focus and depth of field seen in the image. The high ISO was not grainy or noisy because the shutter speed was short. This created a sharply focused image despite the size of the aperture.

This image was post-processed using Photoshop. The image was cropped and converted to black and white. Figure 2, the original image has several smudge marks from scratches and clumps of shampoo that take away from the image. These were removed using the clone tool.

This image not only reveals a complex instability, but the beauty of a fluid flow. The conversion of the image to black and white adds an eerie feeling to the image and makes it appear as lightning. The visual "echo" seen by the shampoo "gripping" the lower, blue plate adds to this effect and draws the viewer in in attempts to see more. I would like to design a mechanized system that takes advantage of this beautiful phenomenon and takes on a mechanized sculptural art.

Sources

H. Darcy, Les Fontaines Publiques de la Ville de Dijon, Dalmont, Paris (1856)

Shelley, Michael J. "Hele - Shaw Flow and Pattern Formation in a Time-dependent Gap."*Nonlinearity* 10 (1997): 1471. Print.

White, Frank M. *Fluid Mechanics*. New York: McGraw-Hill, 2008. Print.