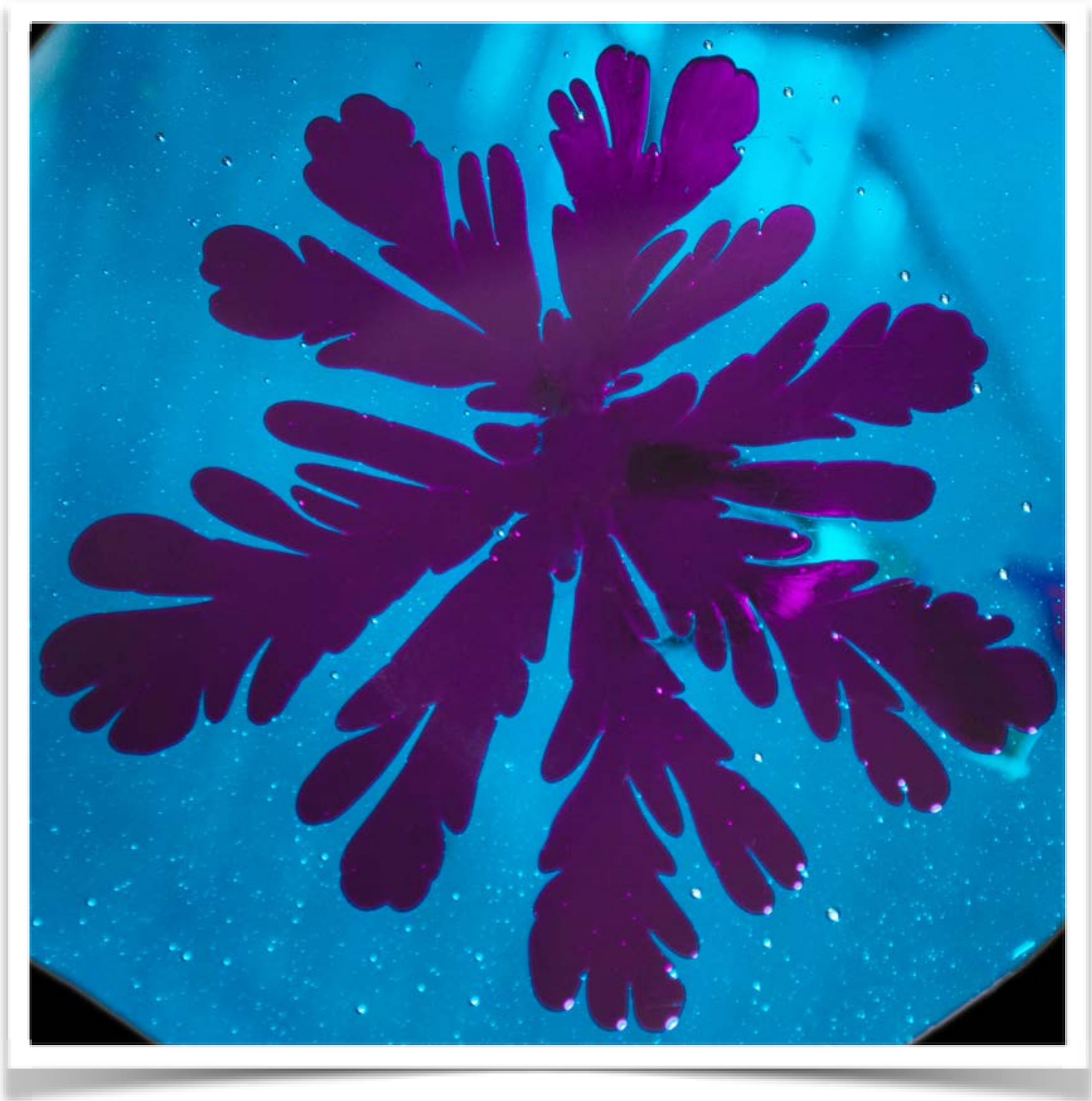

Jason Brownstein

Flow Visualization

Team Picture #1
Spring 2014

In accordance with:
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Purpose:

The purpose of this image is to further advance the skill of flow visualization with the use of teams instead of solo experimentation. It helps to work in teams in order to achieve a higher quality experiment with a more extravagant phenomena. This group consists of Benjamin Healy, Ryan Lumley, and David Zilis. In this experiment an existing set up is used to eliminate the difficulty of building a set up so the group would be able to focus on achieving the best image or video of the fluid phenomena. The Saffman-Taylor Instability is imaged in this experiment.

Flow Set-Up:

Figure 1 shows a Hele-Shaw cell. This apparatus aids in the visualization of the Saffman-Taylor Instability. The box itself is 2' deep by 2.5' wide. On the outer edge of the box is a PVC tube that is cut in half to act as a drain gutter for the fluid as it flows off the top glass surface. There are two panes of glass that are separated by set screws. It is important for the two panes to have a minimal distance between them in order to squeeze the fluid onto the surface and eliminate air bubbles. In the center of the bottom pane is a hole (not shown in figure 1) for a piece of 1/8" tubing to be inserted. This tubing allows for a different fluid than the one placed on the glass pane to be injected from below. A syringe was attached to the other end of the tubing and filled with a less vicious fluid than the fluid on the glass pane. This difference in viscosity is crucial to the Saffman-Taylor instability. Figure 2 shows the set up in the lab.

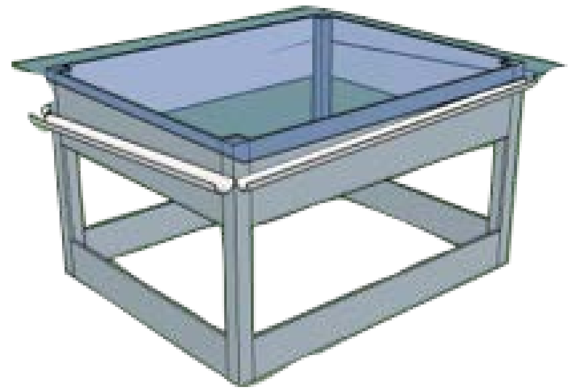

Figure 1: Hele-Shaw Cell

Two constant intensity halogen studio lights (600W, 3200K) were used to supply light from above the

Figure 2: Experimental Set-Up

Hele-Shaw cell while one was used below the cell to add contrast to the two fluids on the cell. One light on either side of the cell was used to eliminate all shadows that could be cast on the glass surface. These lights were roughly four feet diagonally away from the cell. The PVC drained to a trash can to minimize a mess. The camera was placed directly over head of the cell and shot by hand, no tripod was used in this image. The camera was approximately two feet away from the fluid motion and the top face of the Hele-Shaw cell. Having the camera directly above the glass resulted in an image with little to no reflection from the lights or the camera itself. Different angles of attack were used and directly above or nearly directly above turned out to be the best.

Flow Physics:

To achieve the image in this experiment the fluid follows an instability called the Saffman-Taylor instability. This instability is defined when a fluid of small viscosity drives a fluid of large viscosity.[1] In the case of this experiment the large viscous fluid is the Karo Syrup and the low viscous fluid is the dyed water being injected from below. Initially the Hele-Shaw cell is covered in only the Karo Syrup, then from the tube and syringe below the glass that the Karo syrup is on, dyed water is injected. This injection then creates the fingering pattern that is so unique to this experiment. The amount of fingering has been modeled and characterized by Saffman and Taylor. They discovered that the width and type of finger that is formed is dependent on the wavelength, λ, of the two fluids being used in the experiment. This relation can then form an equation describing the local curvature of the finger, shown below;[2]
Where y is the position along the finger and λ is a ratio between the wavelengths of the two working fluids. Figure 3 shows the experimental results of Couder *et al.* One can see that equation (1) does a

$$x = \lambda / \pi * \ln 1/2(1+\cos(\pi y/\lambda)) \quad (1$$

decent job at predicting the curvature of the developed finger.

This set up uses two parallel plates on the top and the bottom of the fluid. This condition is typical of experimental set ups but having almost no constraining boundary on the fluid in the lateral direction is not and can have an effect on the resulting patterns and finger geometry. In this case the experiment can be considered to be bounded by a circular wall instead of parallel flat walls. In turn the resulting experiment should occur in this order. First many fingers like in figure 3 will form simultaneously, then as they grow past a certain size the tips will destabilize and then form the tiny fingers off of the main finger.[3] This is seen in numerous experiments, this one included.

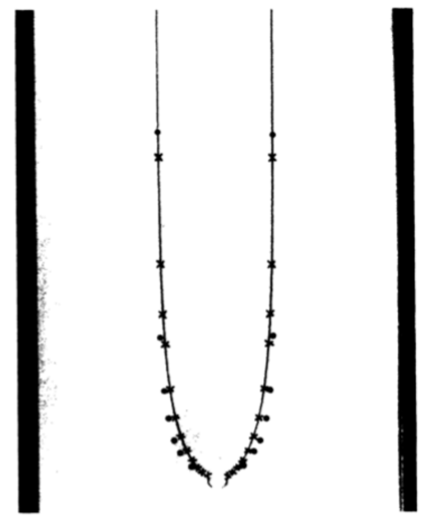

Figure 3: Experimental Photo[2]

The reason for this destabilization and unique growth has been attributed to a couple of forces. First the capillary force, which allows for a fluid to move in narrow spaces without any other assisting force. This force is a resultant of the narrowly spaced plates of glass sandwiching the fluid. The second force acting in this experiment is surface tension, which is the force that will hold a fluid molecule together on the rim of a glass for instance. This force works to keep the boundary between the two different fluids. Finally the velocity at which the low viscous fluid is entering the experiment determines the amount of extra fingering that occurs. As the velocity increases the molecules and their perturbations increase and then destabilize, forming dendrite looking features off of the main fingers. It would have been an interesting experiment to measure the velocity of the incoming fluid and record the differences in finger formation in the instability.

Photographic Technique:

This image was taken with a Nikon D5000 equipped with a 18-55mm focal length lens. The lens was adjusted to a focal length of 55mm in this image to result in an image size of roughly six by six inches. Positioning the camera two feet away from the subject and zooming in resulted in the least amount of glare. A shutter speed of 1/50 of a second was used with a corresponding aperture of *f*/5.6. This combination allowed for the use of an ISO of 200 and eliminated all motion blur that could have been caused by not using a tripod at this slow of a shutter speed. The slow shutter speed was a result of the relativity low light because the only light was coming from the studio lights above and below the Hele-Shaw cell. Depth of field was not crucial for this image so the aperture was chosen as a matter of limiting how slow the shutter speed should go.

After the images were taken the Nikon Raw files were edited in Photoshop's Camera Raw editor. Figure 4 shows the image before editing and the image after editing.
First the image was cropped to focus more on the phenomena at hand, this resulted in an even smaller field of view, roughly four by four inches. The original image was 2848 x 4288 pixels and the final image

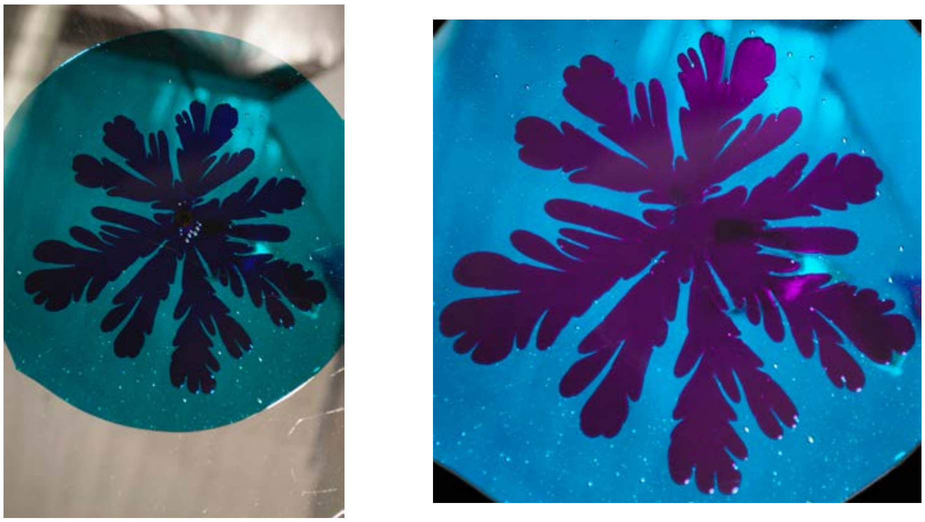

Figure 4: Before and after images

was 2590 x 2562 pixels. Next because the image was taken with a purple fluid going into a blue fluid the white balance of the image was changed. To do this the slider for temperature was moved from 3700K to 3300K. Then a tint of +9 was added to make the image slightly more magenta. Saturation was also adjusted slightly by +20. In the HSL tab blues and purples sliders were adjusted to +33 and +94 respectively in the Hue sub tab and +34 and +37 respectively in the luminance sub tab. These adjustments were intended to increase the contrast in the image and make the purple pop more from the blue fluid background.

Finally in Photoshop, the spot healing tool was used to eliminate all air bubbles and the tube in the center of the image. This tube is crucial to achieving the image but it is not necessary to understand the image and the phenomena. Cracks and scratches in the glass pane were removed with the clone stamp tool. In an effort to draw more attention to the center of the image the white background was made black to create a sort of vignetting. This effect is artificial and not a result of the camera focal length.

Conclusion:

Overall this image and experiment was quite successful. Having a pre made apparatus made for a quick start to the experiment allowed for more time to adjust fluid types and fluid delivery techniques. Karo syrup as a high viscosity fluid injected with food coloring dyed water, a low viscosity fluid, proved to be the most visually appealing in this set of experiments. Attempts with air and Karo syrup, soap and Karo Syrup, and dyed water and soap were all nice to see in person but were quite difficult to capture. This could be a result of the slightly tinted top glass pane that reduced the contrast between the two fluids and gave a false color on the camera. Or it could be a result of lighting in which there was not enough light to properly capture the difference in color. Reaction to the image was positive with some liking the addition of black to the corners while some not liking that addition. It has been chosen to leave the black corners at the artists discretion. It is recommended to seal all PVC joints before beginning the experiment to avoid a messy clean up in the end. As well avoid reducing the set screw length completely on the top pane of glass because it will cause an unwanted suction on the tubing and not allow the flow of the less viscous fluid to be injected into the highly viscous fluid. This flow is best visualized with film and not still images. It is quite brilliant to see the flow develop as one fluid is injected into the other. While a still image is beautiful, it does lack a sort of dynamic that the fluid phenomena requires.

References:

1. Tabeling, P., G. Zocchi, and A. Libchaber. "An experimental study of the Saffman-Taylor instability." *Journal of Fluid Mechanics* 177 (1987): 67-82.
2. Couder, Y., N. Gerard, and M. Rabaud. "Narrow fingers in the Saffman-Taylor instability." *Physical Review A* 34.6 (1986): 5175.
3. Thomé, H., et al. "The Saffman–Taylor instability: from the linear to the circular geometry." *Physics of Fluids A: Fluid Dynamics (1989-1993)* 1.2 (1989): 224-240.