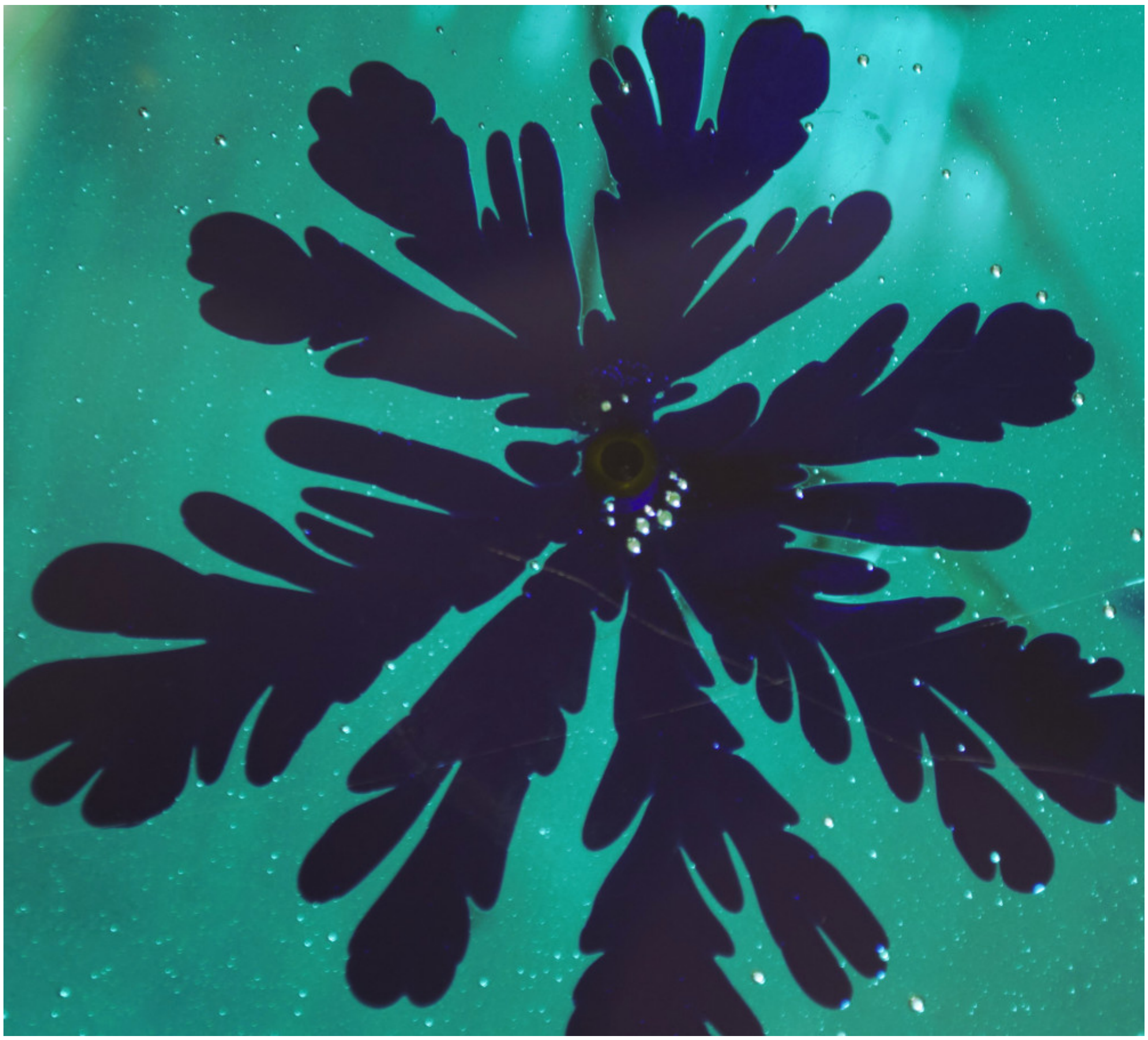
Team Project 1



MCEN 5151 – Flow Visualization

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Introduction:

The purpose of the team image is to capture a beautiful flow image that is a little more complex than the Get Wet image. Our team decided to capture the viscous fingering of a Hele Shaw cell. We chose this because it's a relatively simple set up that produces gorgeous, almost surreal looking images. After many trial, we eventually decided to go with cool colors because they showed up and paired together very well.

Physics:

A simple schematic showing the flow set up is shown below in figure 1. Dyed corn syrup was pressed between two sheets of acrylic that were very close together. Then, dyed water was injected through the bottom acrylic into the gap containing the corn syrup. For this particular image, there were three light sources, two from above and one from below. The picture was taken from directly above with the camera about 8 inches away. The field of view is about 5 inches.

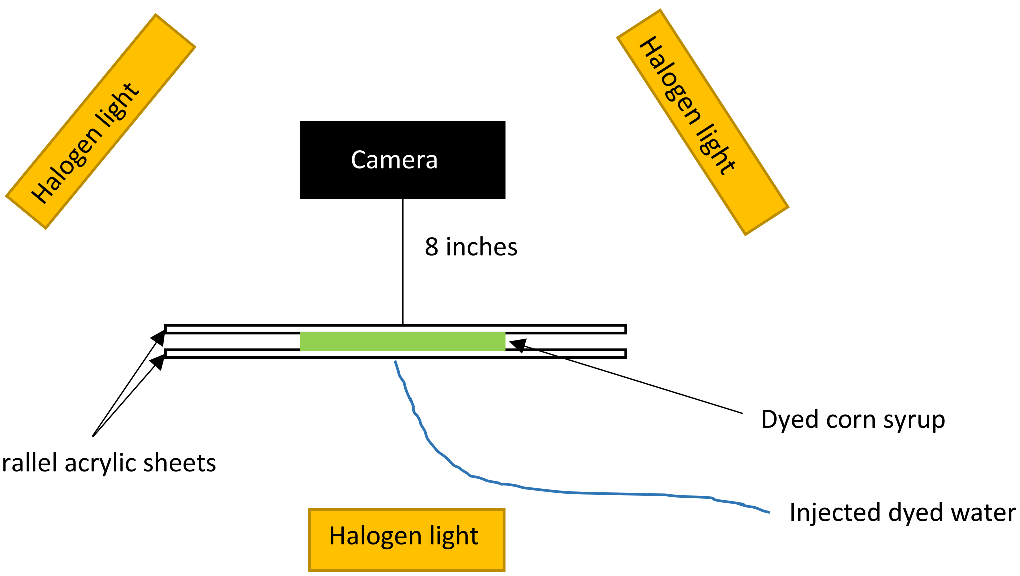

Figure 1 - Schematic of the Experiment

The Hele Shaw cell was actually made as an analog for investigating two dimensional flow in a porous media[1]. It is based on the fact that the differential equations governing flow in a porous medium are very similar to those governing viscous flow between two parallel planes. In a Hele Shaw cell, flow velocities are extraordinarily small which give Reynolds numbers close to zero. These low Reynolds number flows are called Darcy flows[2]. In Darcy flows, instabilities are typically driven by viscosity instead of density[3]. This instability is defined by the fingers of the lower viscosity fluid penetrating into the more viscous fluid[1].

Visualizing why the fingers occur is actually fairly straight forward. When initially injected, the water forms a circle as one might expect. Then as this circle grows, it hits some inhomogeneity in the more viscous fluid. This causes the circle to become more wave like and the water then expands out through those waves creating fingers[1]. Fingering occurs once the circumference of the circle of water is equal to the critical wavelength. This critical wavelength is represented by the equation below[1].

$$\lambda_C = \frac{2\pi R}{\left(\left({QR}/{2\pi M\sigma} + {1}/{4}\right)^{1/2} - {1}/{2}\right)}$$

Where R is the radius of the circle, Q is the flow rate of the fluid, M is the fluid mobility of the water (based on viscosity and the gap between the two acrylic sheets), and σ is the surface tension[4]. This is an equation that unfortunately I cannot solve because I didn't know to record things like flow rate and gap size at the time the image was taken.

To summarize, Hele Shaw cells have very, very low Reynolds numbers, which leads viscosity based instabilities described by Darcy's law[4]. When water is first injected, it forms a circle in the more viscous corn syrup. However, as this circle expands, it hits inhomogeneity in the corn syrup. When the water circle is above a certain critical circumference, fingering forms and propagates. This circumference can be determined from Darcy's law and is given above.

Photo Setup:

The setup for this photo was relatively simple. Corn syrup was placed between two large, clear acrylic sheets. The bottom sheet had a small hole with a tube coming out of it. Water was then injected through this tube, into the corn syrup. The apparatus used to hold the plates parallel and slightly apart was quite large and was made of wood painted black. This black wood showed up in the photos and was distracting, so printer paper was used to cover the black. The process of choosing colors to inject was a long one. We tried many different pairings and decided that clear water was not interesting enough, and the warm color dyes didn't really contrast enough considering the light was fairly yellow. For this reason, we decided to use two contrasting cool colors. The lighting is standard halogen photography lighting. Its set up is shown in figure 1.

As for the actual experiment and photography, the camera was placed directly above the acrylic, about 8 inches away. The corn syrup was about 6 inches in diameter when pressed between the sheets. The flow was very easy to photograph because it moves so slowly. I could easily inject water until the fingering was large, go get my camera, and take the pictures without losing any information in the flow.

Photo Technique:

The photos were taken with a Canon EOS Rebel T2i D-SLR camera. The original photo can be seen below in figure 2.

Figure 2 - Unedited Get Wet image

The field of view in this image is about 5 inches by 8 inches with pixel dimensions of 2848x4287. The photo was taken with the camera about 8 inches away. The lens used was just the stock lens that came with the camera. It has a focal length of 18-55 mm and a focus distance of 0.8 ft to infinity. For this image, a shutter speed of 1/50 s, an aperture f-stop of f/5.6, and an ISO setting of 200 were used. These values are the ones the camera picked automatically. I know it's possible to get cooler pictures by tweaking those values, but it seems that when I try to do it the image just gets worse than the automatic settings. Therefore, I decided to just let them be.

After the image was taken, there was some minor post processing done in Gimp. The image was obviously cropped to focus on the flow phenomenon. The cropped image had pixel dimensions of 2514x2271 and the field of view was reduced to about a 5 inch square. After cropping, I played around with colors a little bit. When I increased the background green significantly, I got a color combination I liked more and some of the distracting things in the back (glare, tube, etc.) became less noticeable. I also spent a significant amount of time trying to get rid of the scratches in the glass and the tube in the middle of the flow, but couldn't do it. Every time I tried, the photo looked obviously doctored which, to me, is more distracting than the scratches and tube.

Conclusion:

I feel this image does a great job of capturing a Hele Shaw cell. Not only does it show the phenomenon clearly, but it's a pretty photo as well. However, there are a few things I'm not too happy about in the image. Despite my best efforts, the scratches, tube, and glare in the background are still there. In the future, I will talk to someone who knows how to use Gimp well to see if I can get rid of those distractions. To develop this idea further, I would record more experimental values. With flow rate and gap distance, I could have used the equation found to calculate when fingering would occur. I could then compare this finding with the experiment which would be very interesting.

References

1. Paterson, Lincoln. "Radial Fingering in a Hele Shaw Cell." *Journal of Fluid Mechanics* 113 (1981): 513-29. *Cambridge Journals*. Cambridge University Press, 20 Apr. 2006. Web. 18 Mar. 2014. <http://journals.cambridge.org/download.php?file=%2FFLM%2FFLM113%2FS0022112081003613a.pdf&code=9d770ac209c2f1498a9e7b504bdd5319>.
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