Team Assignment #1 Write-Up

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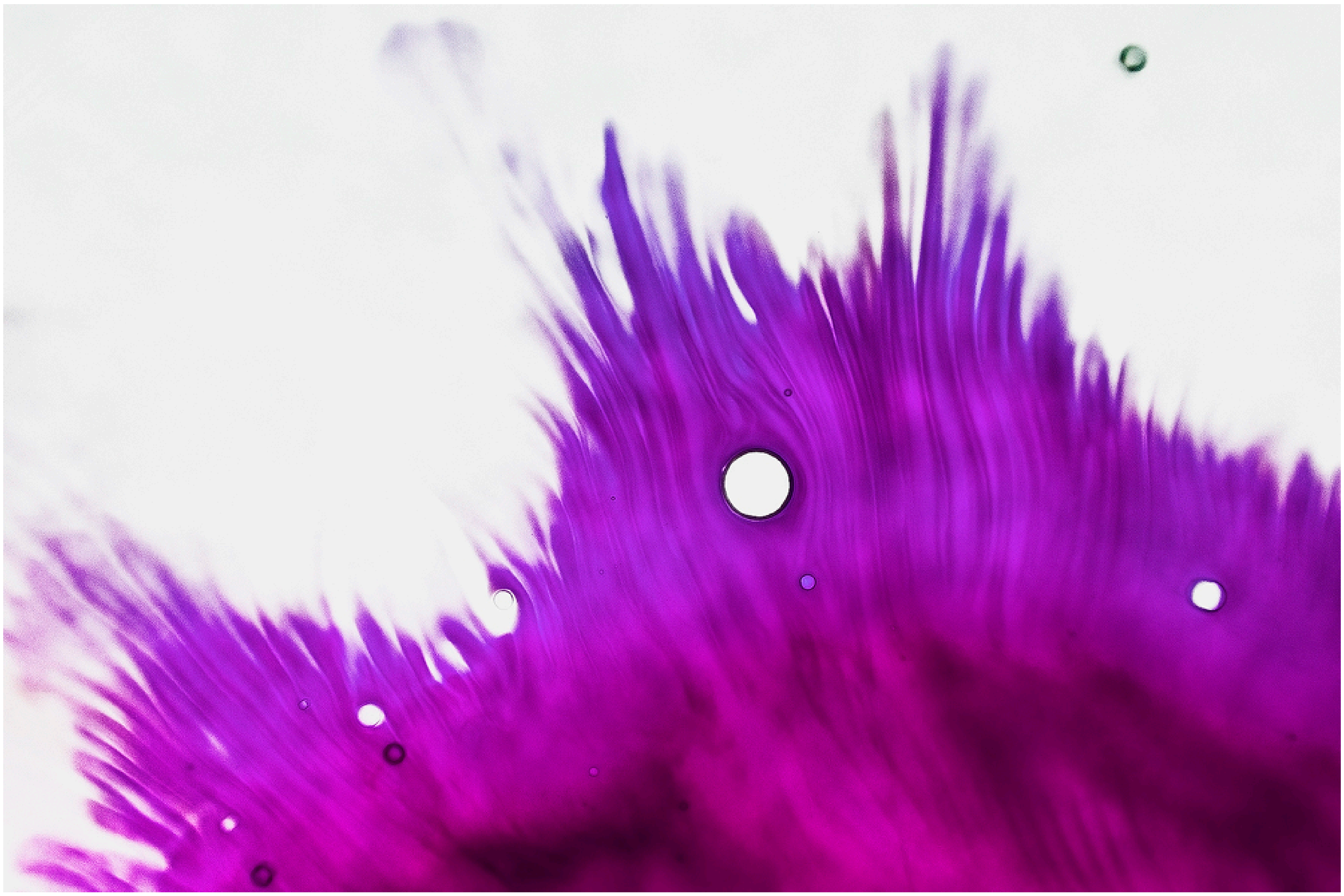
Flow Visualization – MCEN 5151

3/19/13



I. Introduction

For Team assignment #1, my goal was to design an experiment that allowed for an interesting, close-up, macro view of a fluid flow. Macro photography of fluid flows is difficult to do, however the images can reveal much more of the actual dynamics and minute details than their non-macro counterparts. In order to capture this, I created a Hele-Shaw cell, which can best be described as a two parallel plates separated by an infinitesimally small gap, of which fluid is injected into with varying viscosities. It is the viscous creep that is caused when a less viscous fluid is injected into the more viscous fluid in the Hele-Shaw cell that I was intending to capture. My final image can be seen below in Figure 1.

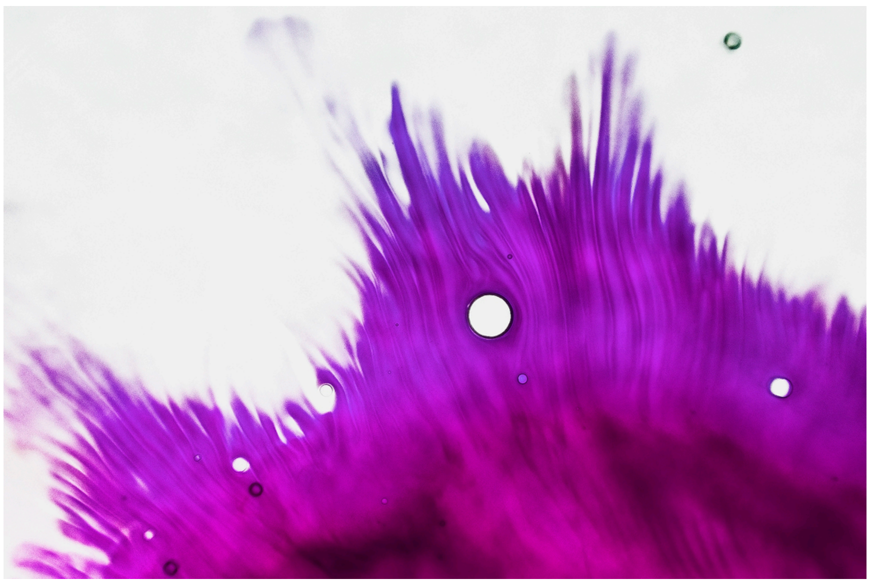


Figure 1 - Final edited image

II. Flow Apparatus

As mentioned above, the flow induced in the Hele-Shaw cell was caused by first injecting a very viscous fluid, corn syrup in this case, into the gap between the parallel plates. After filling the space between the plates with the viscous fluid, the less viscous fluid, water with food coloring, was injected with a syringe. The flow movement can best be visualized using Figure 2.

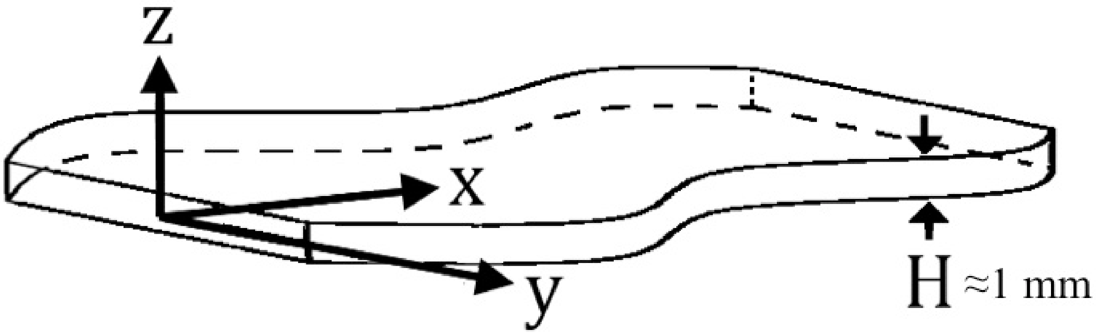


Figure 2 – Hele-Shaw cell flow [1]

In Figure 2, you can imagine that the upper and lower flat areas are bounded by the two parallel plates above and below. When the fluid is injected via the syringe through a hole in the upper plate, the flow has nowhere to move except outwards, in the X & Y directions. H is the thickness of the fluid, which was roughly 1 mm in this Hele-Shaw cell.

One of the main reasons that Hele-Shaw cells are used for flow visualization is for visualizing very slow flows with low Reynolds numbers. The flow through the Hele-Shaw cell is technically classified as Stokes flow, which can best be explained as a type of fluid flow where inertial forces are small compared with viscous forces. Stokes flow does occur naturally in nature, one example being lava flow. The Reynolds number is very low, i.e. Re << 1, signifying that the flow is very slow moving, laminar, and dominated by viscous forces.

In this case in particular, the Reynolds number could be calculated using

$$\mathrm{Re} = \frac{\rho \mathrm{v} L}{\mu}$$

Where ρ is the density of the fluid, v is the velocity of the fluid, L is the traveled length of the fluid, and μ is the dynamic viscosity of the fluid. In this case the density of the water is $\rho = 1000\, {}^{\mathrm{kg}}/_{\mathrm{m}^3}$, the velocity is estimated at roughly $\mathrm{v} = 0.01\, {}^{\mathrm{m}}/_{\mathrm{s}}$, L = .05 m, and the viscosity of the corn syrup is μ = 1.3806 Pa*s. This yields a Reynolds number of:

$$\mathrm{Re} = \frac{\left(1000\ {}^{\mathrm{kg}}/_{\mathrm{m}^3}\right) \text{ x } (0.01\ {}^{\mathrm{m}}/_{\mathrm{s}}) \text{ x } (.05\ \mathrm{m})}{1.3806\ \mathrm{Pa} * \mathrm{s}} = \mathbf{0.362}$$

As mentioned earlier, due to the low Reynolds number of the flow, the flow is deemed laminar, meaning that the fluid flows in parallel paths, with no disruption between the layers and no eddies. There is friction between the fluid and the two plates on the top and bottom, causing the velocity of the fluid to be lower than in the middle of the plates. The velocity profile can be seen in Figure 3.

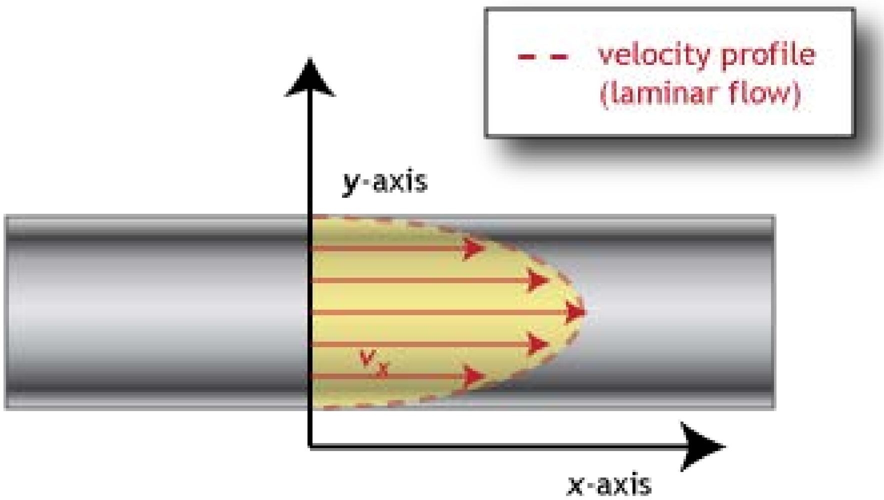


Figure 3 – Laminar flow velocity profile [2]

III. Visualization Technique

In order to make the Hele-Shaw cell, clear acrylic was used to make the two upper and lower plates. The two plates were 12 x 12'', and a $^{1}/_{16}''$ diameter hole was driven in the top plate to inject fluid into. In order to ensure the constant yet very small gap between the plates, 1 mm thick glass microscope slides were placed around the edges of the plates and then the plates were clamped along each edge. This can be seen in Figure 4.

The viscous fluid, corn syrup, was placed in the center of the bottom plate, and then the upper plate was secured on, spreading out the corn syrup evenly. Both blue and red food dye was placed in the non-viscous fluid, water, which was then injected via a syringe through the center hole. Injecting various colors of water allowed for unique color combinations.

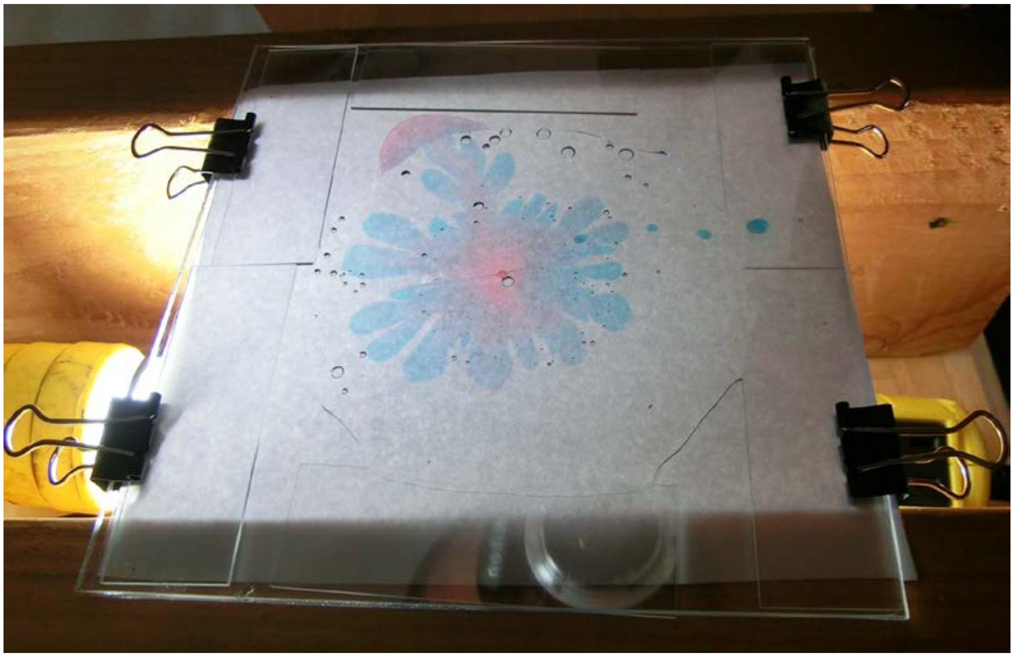


Figure 4 - Hele-Shaw Cell Setup

Lastly, in order to allow even lighting from beneath, a sheet of computer paper was placed along the underside of the cell, and a light was placed underneath it while the cell was propped up on some pieces of wood.

IV. Photographic Technique

A 12.3 megapixel Nikon D90 DSLR was the camera used for this photo which yielded a photo 4288 × 2848 pixels. The reverse macro technique was utilized in order to take the macro fluid image, which means that a lens was disconnected from the camera, rotated around backwards, and held manually up to the camera body, which surprisingly acts as a macro lens. Due to the fact that the camera was not connected to any lens, the camera would not focus or set the settings for the photo so a manual aperture on the lens had to be set and manual photo settings on the camera body as well. The lens used was a Nikkor 50mm f/1.8. The manual settings chosen were a shutter speed of $^{1}/_{200}$ sec, an ISO of 200, and an aperture of f/1.8.

Adobe Photoshop CS5 was used for post processing. Various color balances were changed, the curves and levels were altered, as well as contrast, brightness, and the clone stamp tool was used to remove the outer ring of the corn syrup. The main goal was to make the color of the fluid really pop, and ensure the background was a uniform white that did not detract from the flow. The before and after images can be seen below in Figure 5.

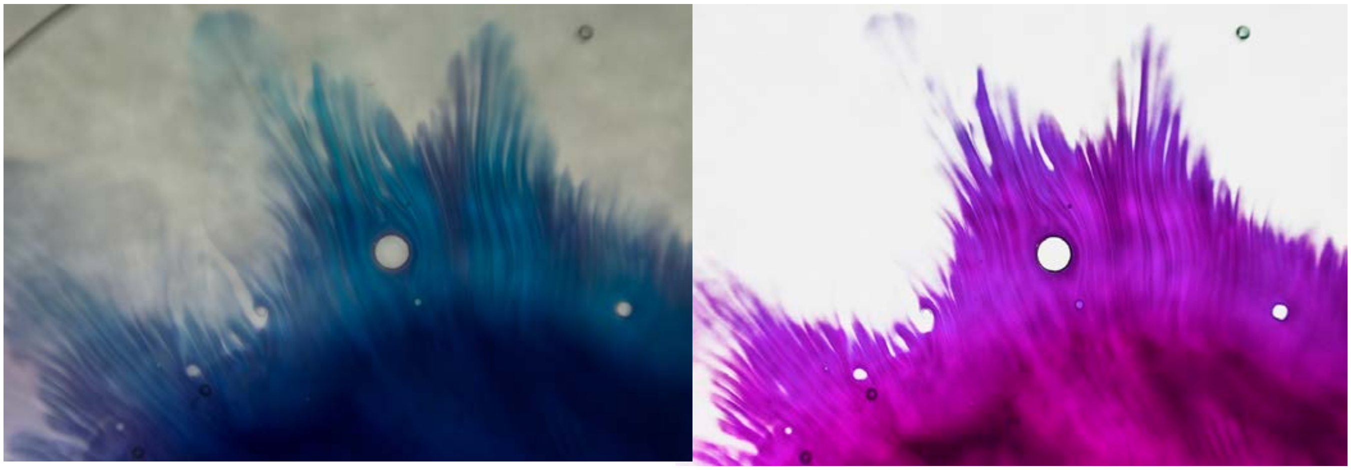


Figure 5 – Before and after processing

V. Conclusion

In the end, I was very pleased with the result. The Hele-Shaw cell allowed for great fluid visualization, the reverse-macro lens technique allowed for very close-up and sharp images, and the post-processing did an excellent job of really making the image pop. The image shows the fluid forcing itself around air bubbles caught in the corn syrup added some unique physics as well. Next time, I would try experimenting with more color combinations and different viscous and non-viscous fluids. Overall, I am very satisfied with the outcome.

Special thanks to Felix Levy, Aaron Lieberman, Ross Pitcairn, and Gabriel Paez for the assistance setting up.

Sources

1. *Hele-Shaw Geometry*. N.d. WikipediaWeb. 17 Mar 2013. <http://en.wikipedia.org/wiki/File:Hele_Shaw_Geometry.jpg>.

2. *Velocity Profile of Laminar Flow*. N.d. Access AbilityWeb. 17 Mar 2013. <http://accessibility.psu.edu/longdescription>.