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MCEN 4151
Group 2 Report

For the second group project in the Flow Visualization class at the University of Colorado, Janelle Montoya and I decided to use the Hele Shaw Cell. After seeing examples of fluid flow from the Hele Shaw Cell, the intent became to take a picture with high contrast that showed the fluid phenomena well. Originally, the main goal was to capture the propagating "fingers", however this proved to be quite difficult. With this realization, my goal was to capture a unique picture of fluid flow using the Hele Shaw Cell. I had help setting up the Hele Shaw Cell, which is depicted in Figure 1, by my team mate, Janelle Montoya.

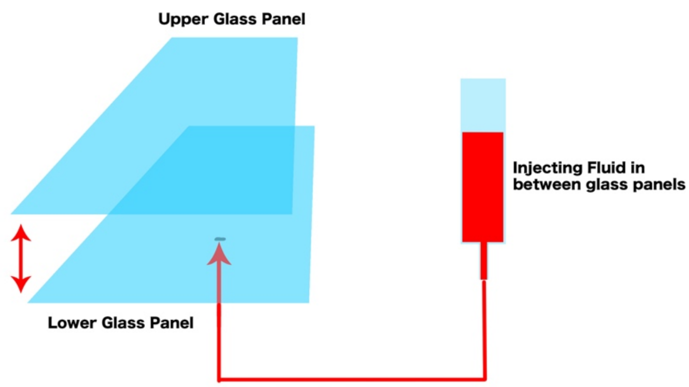

Figure 1: A representation of the Hele Shaw Cell.

The flow apparatus used for this image was the Hele Shaw Cell. It is essentially two pieces of glass or acrylic separated by very small distances. The separation can be adjusted. One piece has a small hole in it, which allows for a fluid or gas to be injected in between the glass or acrylic sheets. For the picture in this report, air was injected into red ink. The Hele Shaw Cell that was used measured roughly 18" x 24". Again, Figure 1 is a representation of the Hele Shaw Cell that was used. The flow phenomena known as the Saffman Taylor Instability, occurs when a fluid is injected into another, more viscous, fluid. This instability is easily visualized using the Hele Shaw Cell. Mathematically, this phenomenon can be generalized using Darcy's Law for the body of the fluid and a boundary condition to describe the interface between the two fluids. Equation 1 is the derived Darcy's Law equation for a Newtonian fluid, provided by S. Morra and M. Manna.

$$\langle v \rangle = \frac{|\nabla P| b^2}{12\eta} * \frac{\nabla P}{|\nabla P|} \qquad (1)$$

This equation essentially relates the pressure differential, ∇P, and the velocity of the fluid, v, in terms of the distance between the plates, b, and the viscosity of the fluid, η. With the experiment occurring at roughly 20 degrees Celsius, the viscosity of the ink was roughly 4.8 mPa•s. The viscosity of air at the same temperature is roughly 1.845E-2 mPa•s. The spacing between the plates was roughly 0.05mm, measured with calipers. This measurement does not take into account the flexing of the glass at the center of the sheet however.

While the velocity of the fluid could be estimated, the pressure differential would be difficult to derive simply from the amount of unknown variables. Equation 1 can still be used to account for a qualitative reason the Saffman Taylor instability looks the way it does. Essentially, the constant pressure gradient occurring in the injected fluid acts on the displaced fluid. In this case air was acting on the red ink. The air pressure created by the syringe plunger creates a pressure gradient throughout the air as it's injected into the ink. The pressure at the interface of the air and ink acts on the ink, thus displacing it due to the normal forces at each discrete part of ink. The ink and air stay separated due to the density and viscosity differences. The shape of the air bubbles is a result of the air taking the most efficient form for the given force for the given surface area.

Normally, one would expect to see the viscous fingering effect from a Saffman Taylor instability in a Hele Shaw Cell. However, in this picture, there are only bubbles that appear to come from a central injection point. Small fingering effects occur along the air bubble's surface as well. One of the most difficult aspects of modeling the Saffman Taylor instability is from the nonlinearity of real world experiments. This is a result of more viscous and shear forces acting on the fluid as another is injected.

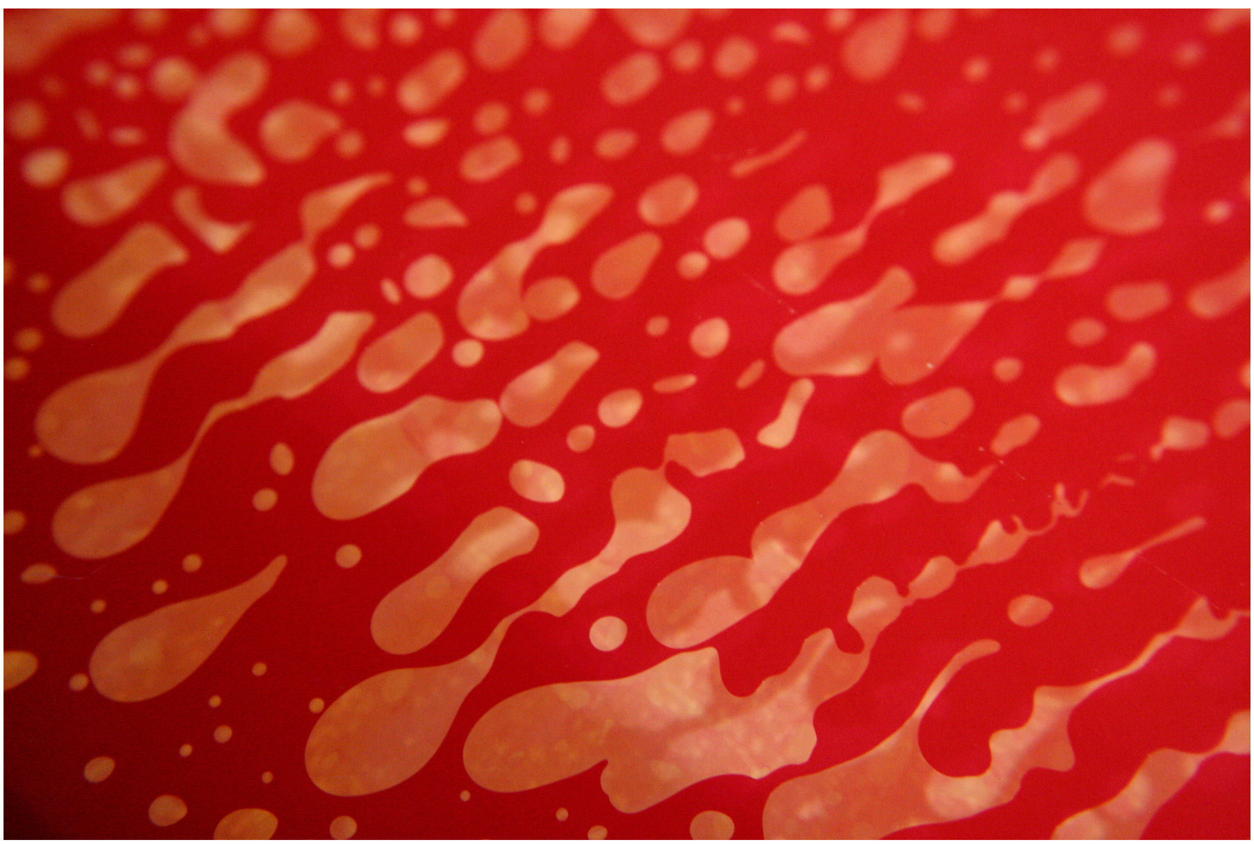

Figure 2: The original image.

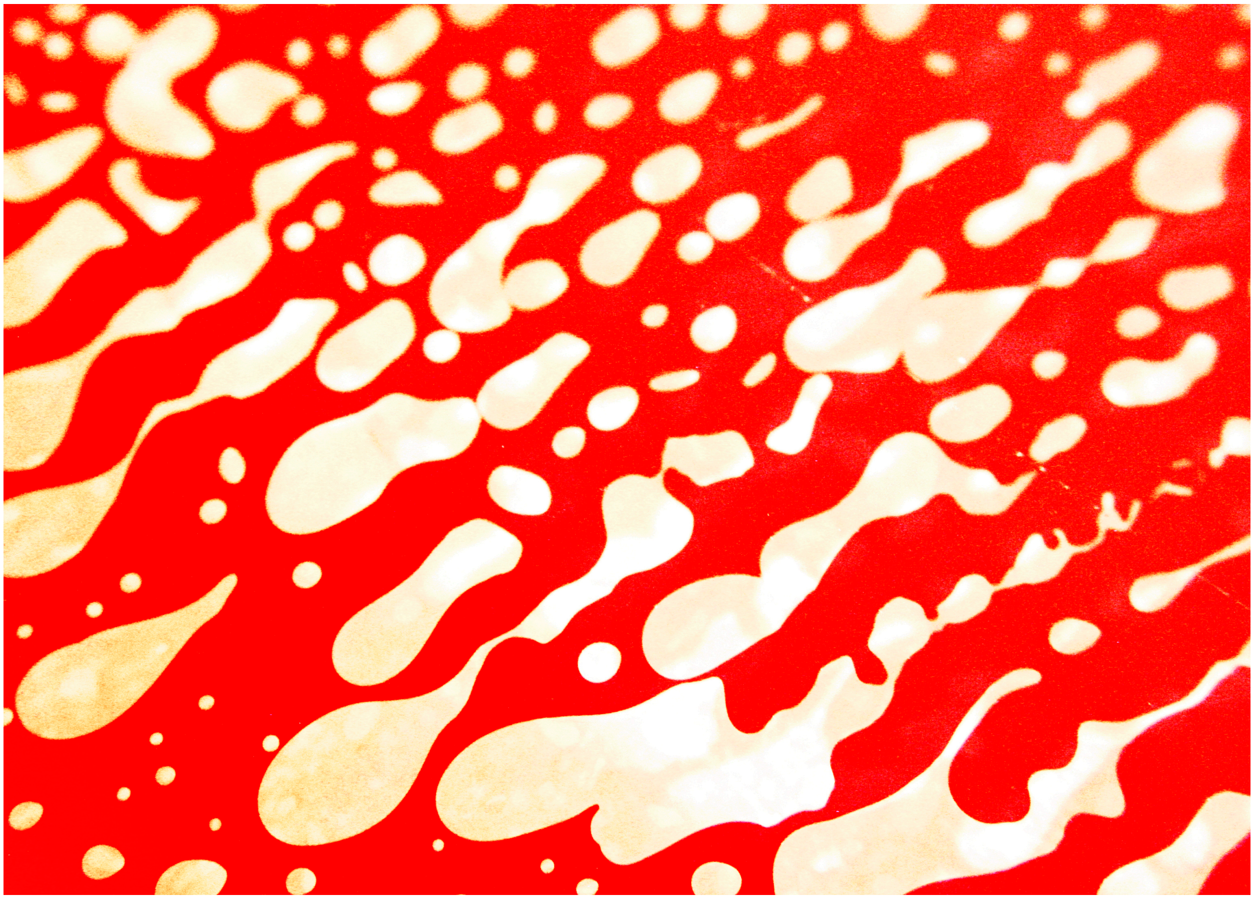

Figure 3: The final edited image.

The visualization technique used was simply red ink normally used for fountain pens. An LED lamp was set to the side of the Hele Shaw Cell pointed directly down at the middle of the glass sheet. With the light hitting the glass surface, the camera had to be carefully placed to avoid reflections. This image was taken in a garage, so it was in an isolated environment at a steady 20 degrees Celsius.

A Mercury brand macro lens extension was used with a Canon 18-55mm lens. The camera was a Canon EOS Rebel XT digital camera. The field of view was roughly 1inch x 2 inches with the focal length at 27mm and the lens about 1 inch from the object. The original image was 3456x2304 pixels while the final image was 3068x2192 pixels. The exposure time was 1/50 of a second with an F number at f/5.6 and an ISO of 1600 to account for the relatively low light conditions. The original image was edited mainly using the “curves” function in Photoshop. With the output slope drastically increased a small concave curve was also developed to increase the contrast. The saturation was also increased. The purpose of the manipulations was to increase the overall contrast and obtain a more vibrant photo.

I think this image reveals the bubbles that aren’t normally photographed with a Hele Shaw Cell. I think the image does a good job capturing this phenomena, although there is a heavy abstract feel to it. I found that the fluid physics are incredibly complex with the Saffman Taylor instability. I don’t feel confident that I can model this system without doing it again with expensive equipment in a laboratory setting. This leaves me asking how researchers model physical systems like this? I saw plenty of theoretical calculations, but not once did I see an actual pressure gradient measured. I am also very confused about the boundary condition used to complete the model. I understand what a boundary condition is, however it is difficult to interpret what the model requires. Aesthetically, I fulfilled my intent. Technically, however I feel unprepared to investigate this topic further.

References:

Mora, S., and M. Manna. "Saffman-Taylor Instability for Generalized Newtonian Fluids." *Physical review.E, Statistical, nonlinear, and soft matter physics* 80.1 (2009): 016308. *ProQuest.* Web. 15 Nov. 2015.

Mora, S., and M. Manna. "Saffman-Taylor Instability of Viscoelastic Fluids: From Viscous Fingering to Elastic Fractures." *Physics Review E* 81.2 (2010): 026305. Web. 15 Nov. 2015.