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Hele-Shaw Cell Experiment

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Capturing images of dyed water can create spectacular images. However, this is somewhat of a cliché phenomenon in the world of fluid dynamics and flow visualization. By adding a viscous fluid (corn syrup) for colored water to travel through all between two acrylic plates, an abnormal phenomenon can occur. This technique is called the Hele-Shaw cell experiment [2]. While it has been achieved many times before, there are usually different kinds of fingering and symmetry achieved in each individual experiment, making for a phenomenon with a variety of stunning images. The group consisting of Blake Buchanan, William Pitcairn, Felix Levy, Gabriel Paez, and myself (Aaron Lieberman) attempted to see what type of colors and shapes resulted from the Hele-Shaw experiment.

To create the Hele-Shaw cell, a few materials are needed. Before two clear acrylic plates are set up very close together (a few millimeters) and parallel from each other, corn syrup is spread in a circle on the upper surface of the bottom place. Then the plates are clamped together. Next, a small hole is drilled through the upper acrylic plate so that dyed water can be injected via syringe into the gap in the plates. Finally, to complete the phenomenon, the dyed water is injected at a relatively slow rate into the more viscous corn syrup to portray how water moves in a viscous fluid. The setup can be seen in Figure 1 below.

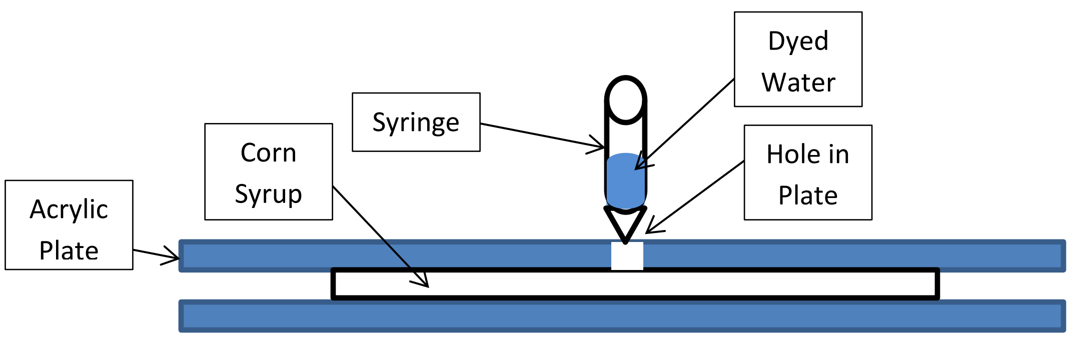

Figure 1: Experimental Setup Side View

At 20 degrees Celsius (about room temperature of 68 degrees Fahrenheit) water's kinematic viscosity is 1.004 m^2/s [4]. Corn syrup's dynamic viscosity is 0.138 Pa*s and its density is 1380 kg/m^3 [3]. This gives corn syrup's kinematic viscosity to be 0.0001 m^2/s. This means that corn syrup, when it is free to expand, moves much slower than water. As the water moves through the corn syrup, it displays a parabolic velocity profile similar to the one shown in Figure 2 [1]. This velocity profile exhibits no slip conditions where the fluid interfaces with the acrylic plates on the top and bottom surfaces, and the maximum velocity of the fluid is exactly half way between the upper and lower plate. This is the velocity profile for fully developed laminar flow.

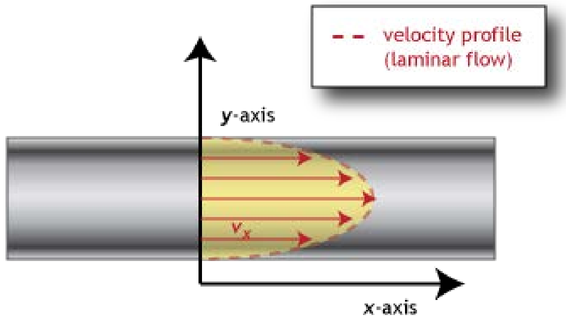

Figure 2: Velocity Profile

In laminar flow, the Reynolds Number is less than 4,000 [5]. This makes sense because the water did not move very fast through the corn syrup. To prove the water is much less than a Reynolds number of 4,000, the Reynolds number equation is shown below in Equation (1).

$$Re = \frac{UD}{v} = \frac{0.01\left(\frac{m}{s}\right)*0.1(m)}{1.004\left(\frac{m^2}{s}\right)} = 9.96 * 10^{-4} \qquad (1)$$

This Reynolds number displays a flow that does not even come close to being turbulent. Because the dyed water only travels about one centimeter per second at its maximum and travels a maximum distance of about 10 centimeters, the Reynolds number is very small and close to zero. This is primarily because the force from the expelling syringe forces the dyed water into the corn syrup. The energy of the water traveling in one direction in the syringe is transferred into kinetic energy traveling in many directions in the corn syrup. Although the water comes out of the syringe at a relatively fast speed, conservation of energy disperses these energies over numerous different directions, making the water flow slowly. To add to this, the corn syrup also acts as a sort of barrier for the water to travel through since it is so viscous the water has to push the corn syrup out of the way to move. Finally, over a small amount of time (about 20 seconds) the dyed water comes to a stop in the corn syrup. This is because the energy in the water is transformed into displacing the corn syrup and eventually the force from the corn syrup pushing inward counteracts the force of the water pushing outward.

To create the nice blue coloring of the fingers in the Hele-Shaw cell, water was colored with blue food coloring. Food coloring was added until a dark blue color appeared in the water. The experiment was under lit with a portable utility light that plugged into a wall outlet. To create a white background but still let light shine onto the Hele-Shaw cell, white computer paper was placed under the acrylic plates. The paper and acrylic sheets were propped up using two 2” X 4” wood pieces, and the light was in between the wood pieces and under the white computer paper. Since the photograph was taken in the afternoon, there was also some sunlight shining through windows that lit the experiment. There was enough light that the flash on the camera was not used.

The field of view in the original image, seen below in Figure 3, is about 14 inches in width and 12 inches in height judging from the 8.5 inch by 11 inch paper used in the experiment. The photograph was taken with a Samsung ST65 digital point-and-shoot camera about 18 inches away from the Hele-Shaw cell to the lens. The lens focal length was 20 millimeters, the exposure time was 1/75 seconds, the ISO setting was 412, the aperture was 4.64, and the F-stop number was f/5. In pixels, the original image was 4224 in width by 2816 in height. In contrast, the final image was 1176 pixels in width and 982 pixels in height after being cropped.

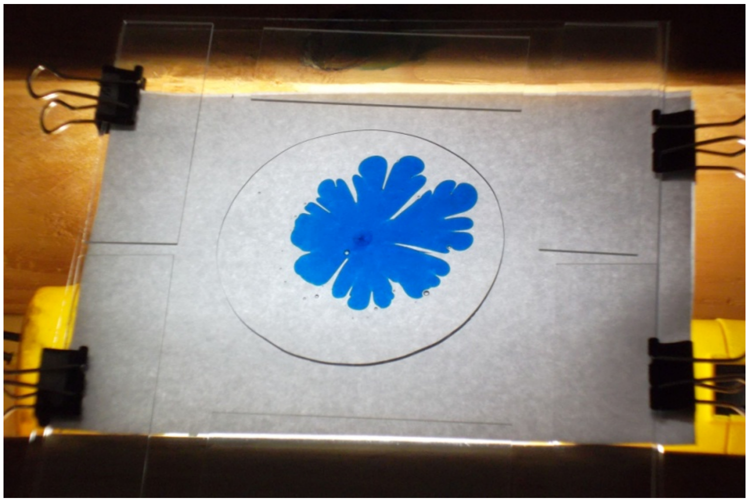

Figure 3: Unedited Image

Little editing was done to the original image. The main edit came from cropping the image so that the fingers of the Hele-Shaw cell are highlighted and the unnecessary clamps and background in the original image are cut out. The only other edit came from slightly adjusting the image using the curves tool in Photoshop to make the blue coloring more vibrant. The final image can be seen below in Figure 4.

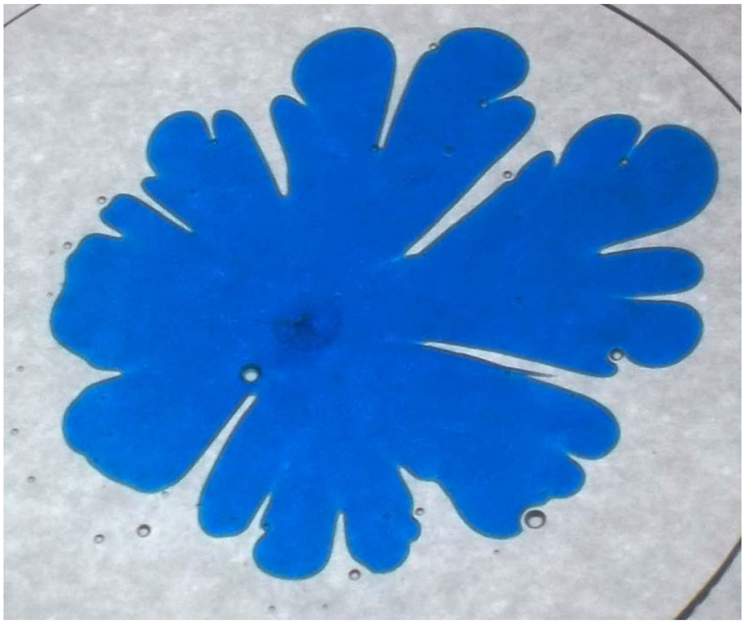

Figure 4: Edited Image

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Overall, the image shows how a low viscosity fluid moves through a high viscosity fluid clamped between two parallel plates. From the top, the Hele-Shaw cell shows how the less viscous fluid creates finger-like protrusions in a symmetric pattern about the hole drilled in the center of the acrylic. This is also a great experiment to display the two-dimensional velocity profile of a liquid between two parallel plates. I particularly like the snowflake type pattern that the fingers create and how they form great symmetry about the origin. To further improve the Hele-Shaw cell experiment, multiple different fluids could have been used in place of the corn syrup or in place of the water to examine how a variety of viscosities interact with each other. It is possible that each combination of fluid creates different symmetry, different fingering, and different velocity profiles. Also, different colors could be used to enhance the image.

References

[1] "Long Description." *AccessAbility*. Pennsylvania State University, n.d. Web. 18 Mar. 2013.

[2] "Tabletop Experiments - Hele-Shaw Cells." *Tabletop Experiments - Hele-Shaw Cells*. N.p., n.d. Web. 18 Mar. 2013.

[3] "Viscosity." - *New World Encyclopedia*. N.p., n.d. Web. 18 Mar. 2013.

[4] "Water - Dynamic and Kinematic Viscosity." *Water - Dynamic and Kinematic Viscosity*. N.p., n.d. Web. 18 Mar. 2013.

[5] Young, Donald F. *A Brief Introduction to Fluid Mechanics*. 4th ed. Hoboken, NJ: Wiley, 2007. Print.