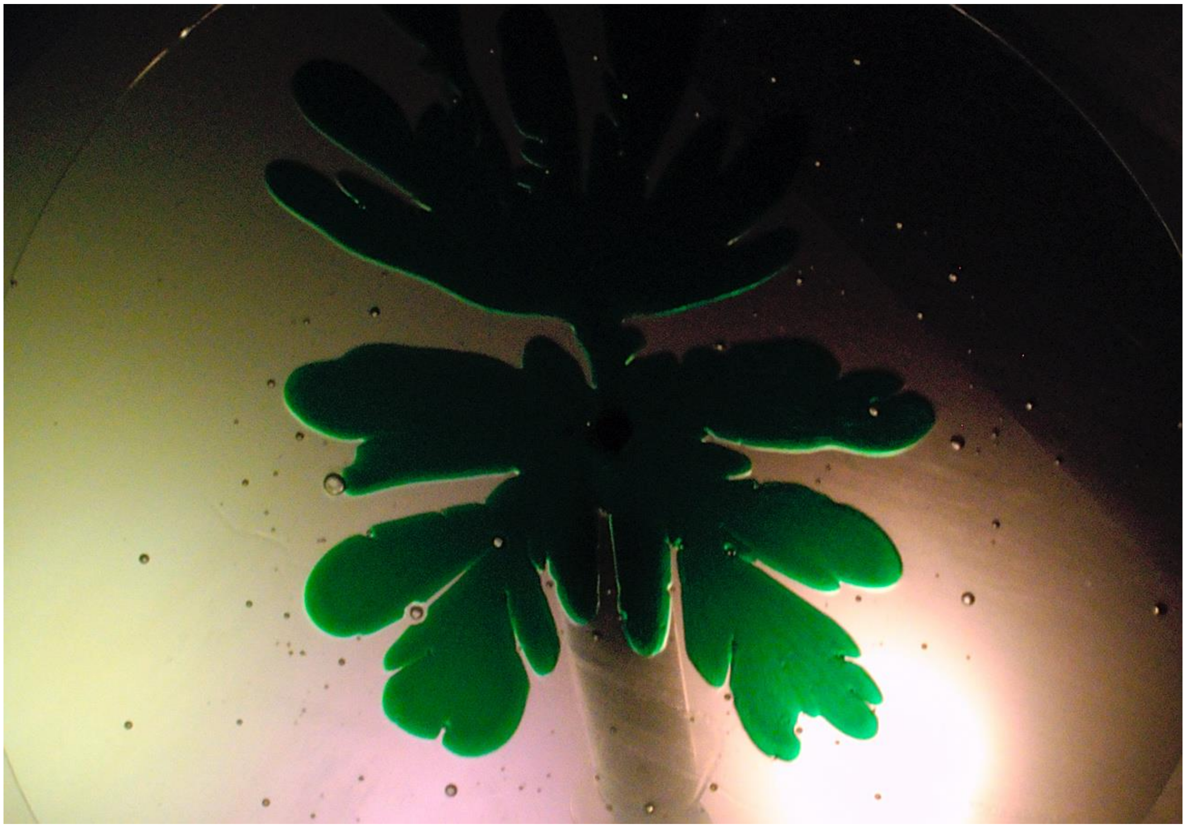

Team Second Image Report

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This photo was taken for the team second image. We set out to try and capture the Saffman-Taylor instability between two fluids in a Hele-Shaw cell. This phenomenon results in the formation of viscous fingering when one fluid of low viscosity flows into another of much higher viscosity. These viscous fingers are quite counter intuitive and often have a very unique and interesting appearance. My intent was to capture the beauty of this unique phenomenon while showing off the fluid mechanics driving its formation.

The chosen fluids were water and corn syrup. The water was dyed with green food coloring to help visualize the flow and add some artistic expression to the image. The food coloring did not significantly affect the properties of the water or the formation of the instability. The set up used was a Hele-Shaw cell provided by Professor Hertz-Berg. A Hele-Shaw cell consists of two clear flat plates with a source of light below them, a phone light in this case with a diffusing layer of glass above it. The more viscous fluid is put on the bottom plate before putting the upper plate on top of it. The thickness of the flow or how far the plates are from one another can be adjusted by tightening or loosening four screws in the corners of the apparatus that held the upper plate up. Then the less viscous fluid can be injected into a hole in the bottom plate using a syringe. This causes the water to flow into the layer of corn syrup and results in the formation of the Saffman-Taylor instability. The setup is recreated below in Figure 1.

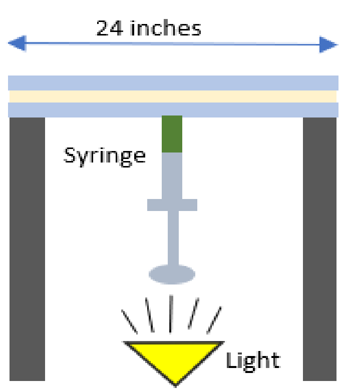

Figure 1: Apparatus

The physics behind the Saffman-Taylor instability can get quite complicated so I will be providing a shortened explanation of the key aspects that result in the phenomenon. First, it is helpful to know that the Reynold's number of a given flow is, so that one can know how the inertial and viscous forces compare and whether one or the other can be ignored. The equation for the Reynolds number is: $Re = \frac{\rho V L}{\mu}$. It essentially is the ratio of inertial to viscous forces in a flow. For this situation the density and viscosity of water are ρ = 997 kg/m^3 and μ = 1.002 x 10^{-3} N·s/m^2 respectively. The approximate velocity of the flow was around V = .06 m/s. The distance between the two plates was roughly L = .001 m or 1 mm. Putting that all together we get Reynolds number of: Re = 59.8. Since this is >>1, it means that the viscous effects in the water flow are negligible. In other words, the water acted as an inviscid fluid.

The underlying causes of this instability and the shapes that form is still not completely understood but they arise from a combination of a few forces. First the surface tension between the fluids works against the flow of the less viscous fluid and helps maintain the boundary between them. The capillary force also plays a role in driving the flow since the gap between the two plates is so small. The pressure difference in the less and more viscous fluid then can cause small instabilities and as the flow develops these instabilities grow into the viscous fingers shown in the image (Saffman). It is also interesting to note that the shape and wavelength of the fingers can be modeled and approximated just by knowing the physical properties of the system and fluids (Chen). This is still an area of active research but there do exist models based off the Navier Stokes equations as well as empirical results derived from experiments (Saffman).

The flow visualization technique was simply dying the water with food coloring so that the contrast between the water and corn syrup was better and easier to see. This gave a clear visualization of the path the water took flowing through the corn syrup. The lighting used in the image was just from a couple phone flashlights underneath the apparatus. The LED flashes from the phones were diffused by a frosted piece of glass. A flood light or some other sort of light source may have worked better as you can see the individual phone lights in the image.

The image was taken on a Nikon D3400. The final dimensions were 1300 x 903 pixels and the original image was 6016 x 4016 pixels. The F-stop was f/25 because I wanted as much light as possible. The exposure was chosen as 1/5 seconds because the image was taken in low light conditions. The ISO was 4000 for the same reason, I wanted to capture as much light as possible while still keeping the quality of the photo. The focal length was 38 mm and the aperture was 4.5. For reference, the original unedited image is shown below in Figure 2.

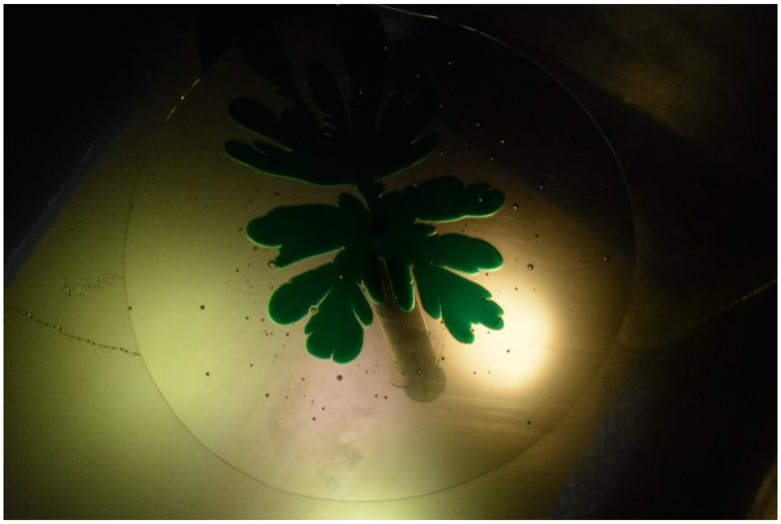

Figure 2: Unedited Image

I personally really enjoy the green color of the water and how it is almost symmetrical down the center. It reminds of some seaweed or some underwater plant due to the bubbles in the corn syrup and the diffused lighting underneath the apparatus. I chose to rotate the image so that the symmetry is very clear. I do wish that the lighting was diffused a bit better and next time I would definitely try to use some sort of flood lamp instead of the phone lights. I would be interested in trying this again with some different colored fluids or possibly using more than just two fluids.

Works Cited

Chen, J. -D. "Radial Viscous Fingering Patterns in Hele-Shaw Cells." *Experiments in Fluids*, vol. 5, no. 6, 1987, pp. 363–371., doi:10.1007/bf00264399.

Saffman, P. G. "Viscous Fingering in Hele-Shaw Cells." *Journal of Fluid Mechanics*, vol. 173, 1986, pp. 73–94., doi:10.1017/s0022112086001088.