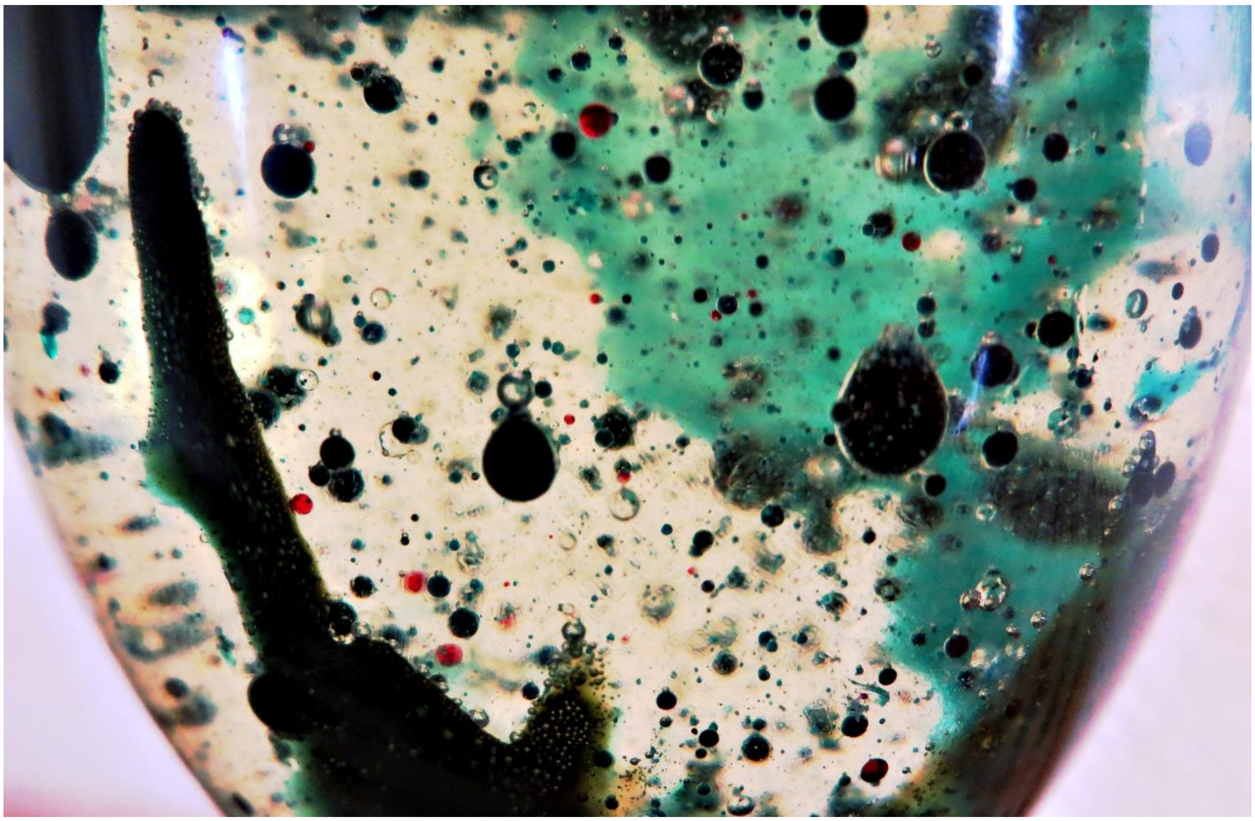

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Flow Visualization – Spring 2018

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Professor Hertzberg

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Introduction

This image was taken for the 2018 spring semester of the course "flow visualization" at the University of Colorado of Boulder. This photo looked to highlight non-diffusive mixing, a type of phenomenon that occurs when fluids of differing densities arrange themselves from most to least dense, as well as the mixing of polar and nonpolar fluids. To create this image, oil, water, food coloring, and a sodium bicarbonate tablet were used. Originally, baby oil was used to try and create a more clear and vivid image. However, the baby oil was not as dense as the vegetable oil, and it made it difficult to catch large droplets. To combat this, vegetable oil was used instead. This report will explain the procedure that was used to obtain the photo as well as the physics behind the final image.

Experimental Setup

The experiment was conducted in a standard-sized wine glass. The wine glass was selected for photo clarity and a wide volume which would allow fluid to move more freely. The wine glass was filled with vegetable oil to 80 percent of the max volume. In a separate dish, a few tablespoons of water were mixed with blue food coloring, and then added to the wine glass. Because of differing densities, the water mixed with the food coloring settled on the bottom of the glass due to non-diffusive mixing. To disturb the fluid and create small droplets, a small tablet of Alka-Seltzer (or sodium bicarbonate) was put into the glass. Once it reached the bottom, it began to dissolve in the water. This created various pockets of gas which forced the water to move throughout the oil. Due to the large difference in densities, the water formed large droplets rather than mixing with the oil. As the reaction occurred, a few droplets of red food coloring were added to the process to create a color contrast. The camera was positioned close to the glass to capture the fluid motion, and was illuminated by natural light filling the room as well as two 125-Watt lamps placed on both sides of the setup. A diagram can be seen below:

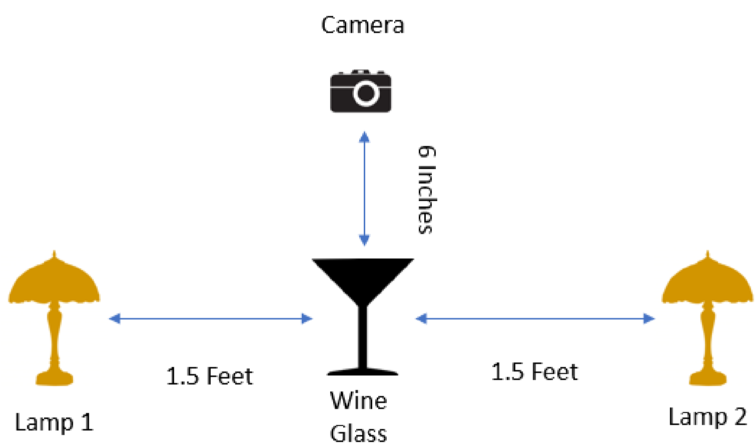

Figure 1: Diagram of setup. Note the close camera placement to the glass, which is useful to capture the fluid in high detail and accurately focus the picture. The wine glass is approximately 7.5 inches tall with 4 inches of height in the section that holds fluids, while the lamps are 6.5 feet in height and were pointed indirectly at the wine glass. The camera was ground level with the wine glass, positioned on an elevated surface.

As water is added to the oil, a small pool of oil forms at the bottom of the glass. This is due to both polarity and a large difference in density, but let's first consider the differences in polarity. A water molecule is a polar molecule, as it has an uneven distribution of electrical charge. That is, the molecule itself is not symmetric meaning charge is not distributed evenly. Oils like vegetable oil however are nonpolar molecules, meaning that it does not have an uneven charge and is symmetric in structure. Polar molecules can form solutions with other polar molecules, and nonpolar molecules can similarly form a solution with other nonpolar molecules. However, polar and nonpolar molecules do not mix due to this difference, and require an emulsifier. [1] Hence, when the oil is combined with the water in the wine glass, the oil remains separate. The reason all the water floats to the bottom of the glass is due to a difference in densities. The density of oil is $\rho = 57.4\ {}^{lb}/_{ft^3}$ while water is slightly denser with a density of $\rho = 62.4\,{}^{lb}/_{ft^3}$. [2] Because the water and oil are opposite polarities, the oil sinks to the bottom. [3] In other terms, the water is slightly "heavier" than the oil, so it sinks to the bottom while the oil remains buoyant on top.

When the Alka-Seltzer tablet was added to the mixture, the aerated solution forces the water droplets to the top of the glass, where they then fall back throughout the oil. To be able to rise to the top, the fluid needs to be able to overcome the pressure force which is being exerted due to the oil. For the calculation, assume the thickness of the water is negligible on the droplets of water, as these will spread throughout the oil. Furthermore, let's idealize the wine glass as a cylinder 4 inches long x 3.5 inches wide. The geometry of the wine glass is a little more complex than this, but this should still provide an accurate measurement. The volume of the wine glass would be:

$$V = \pi r^2 h = \pi(3.5\ in)^2(4\ in) = 153.94\ in^3$$

With this information, the pressure at the bottom of the glass is

$$P = \rho g h = \left(0.0006500276\ {}^{slug}/_{in^3}\right)\left(386.4\ {}^{in}/_{s^2}\right)(4\ in) = .959\ {}^{lb}/_{in^2}$$

Let's also approximate a water droplet as a 4mm (0.15748 in) round surface. This means the droplet has a surface area of 0.019477 in^2. This translates to a force acting on any one droplet as

$$F = Pressure * Area = .959\ {}^{lb}/_{in^2} * 0.019477\ in^2 = 0.0188\ lb$$

Assuming the force of gravity is much less than the force of pressure (as mass of a water droplet is extremely small), this means that the water droplets need to overcome an approximate 0.188 lbs. As the drops rapidly accelerated to the top of the glass, the Alka-Seltzer put out more than enough force to overcome the oil's pressure.

Camera Settings

The photo was taken with a Canon SC260HS with an ISO of 800, f3.5, and a shutter speed of 1/60th of a second. The camera was placed 6 inches from the subject so that the camera could capture the fluid without any distractions. The field of view is 6 inches x 4.5 Since the fluid flow was especially quick, the shutter speed needed to be fast. The room was well lit, so it allowed the photo to be taken with a lower iso and faster shutter speed. The original image had a resolution of 4000 x 3000. To improve image quality, the image was edited using GIMP. The final image had a resolution of 3800 x 2472 after cropping out some of the edge defects. The image also had colors brought out, and was then sharpened to improve clarity. The settings used are pictured below, as well as the original image:

Figure 2: The original image. Notice that the blues have a little more color to them in this image. While this still was a nice effect, the curve used in figure 3 made them much darker in favor of bringing color to the mute reds.

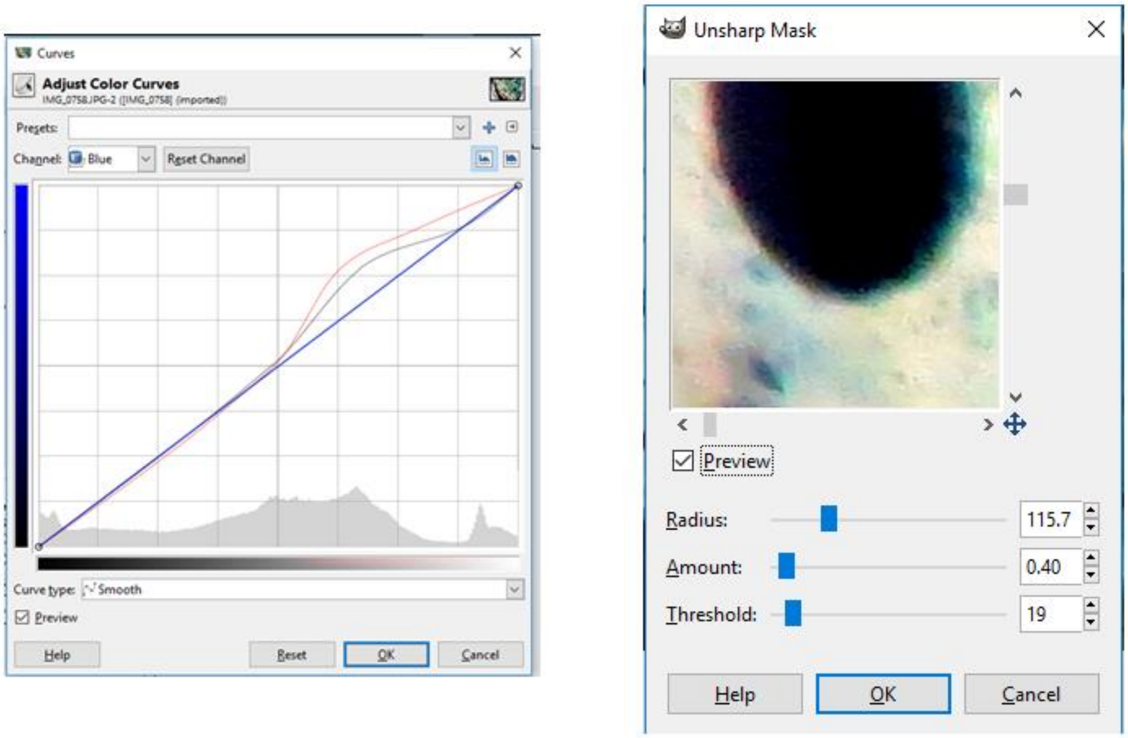

Figure 3: Gimp edits applied to the photo other than the crop. The curve was chosen to try and emphasize the blues more while stretching the contrast throughout the image. Meanwhile, the sharpening effect helped to mitigate the lack of focus of the source image.

Conclusion

The image demonstrated polarity between oil and water in a clear way. Even though the water droplets were distributed throughout the fluid as in the final photo, the droplets did not diffuse into the water. Since the blue food dye was so concentrated, it created a very inky contrast between the yellow oil and the drops of red. The Alka-Seltzer made a very enjoyable, violent flow that can invoke uneasy feelings. Overall, the image illustrates the idea quite well. In the future however, the camera settings can be tweaked even further. One of the biggest problems with the image was a lack of focus in the image. The focus was difficult to get right in the image. Furthermore, the lighting setup could be improved, as the glass experienced some glare due to the natural light in the room. One of the final improvements would be to dramatically scale back the dilution of food coloring and water. While the blue coloring created an almost black ink, it did not provide much room for other colors to mix into this. This is perhaps a matter of taste, but lighter colors could open more possibilities.

Citations

[1] http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page3.html

[2] https://www.engineeringtoolbox.com/liquids-densities-d_743.html

[3] http://scifun.chem.wisc.edu/HomeExpts/layeredliquids.htm