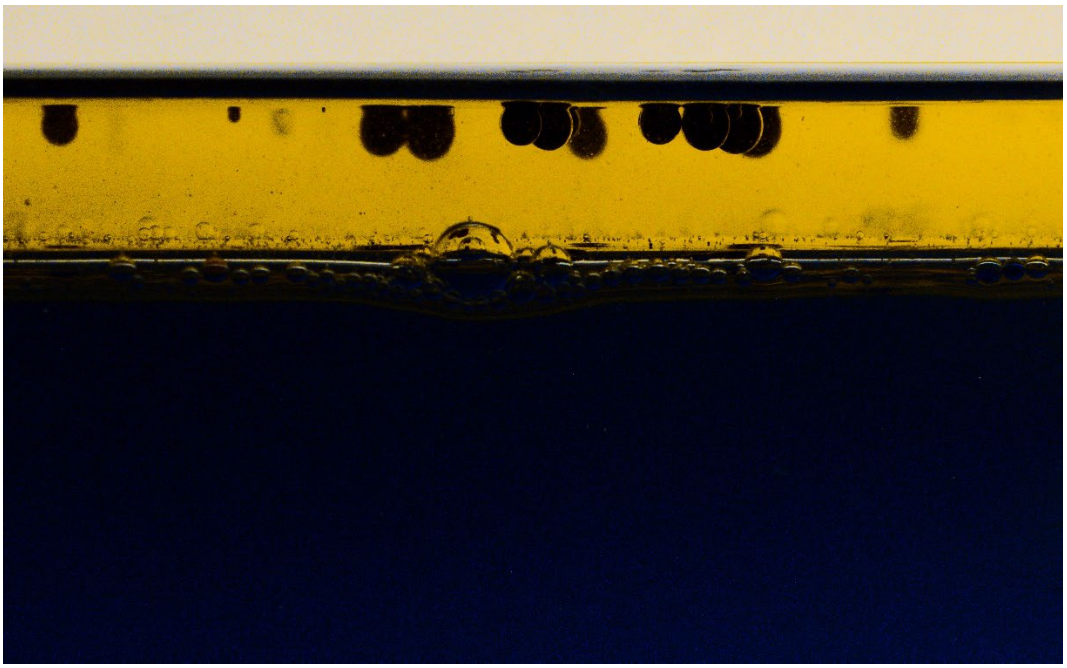

TEAM THIRD

MCEN 5151: Flow Visualization

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Collaboration: Avery Fails, Sarah Hartin, and Izzy Young

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Image Intent

For the third team photo, my group intended to create a boundary layer between water and cooking oil in order to demonstrate the shear forces that exist on the surface of the fluid from a moving Styrofoam plate with a given velocity. This experiment was too difficult to capture on camera with our given environmental lighting conditions. The scientific intent was to exhibit the forces acting on a moving plate over a fluid surface. The artistic intent was to display the varying layers and color differences between the dyed water and the cooking oil boundary layer. This image was an "accidental" image taken during the set-up of the experiment. The artistic intent remained valid with the boundary layer and coloring throughout the layers. The scientific intent shifted during the experiment to exhibit the color dye droplets suspended in the oil prior to falling into the water below.

Image Description

Figure (1) below shows the diagram to recreate this image. This set up included a 15-gallon fish tank with approximately six gallons of water and a 40-ounce layer of Signature Selection 100% Canola Oil. Once the boundary layer was established and settled, a tooth pick covered in blue Wilton food coloring was inserted into the water below the oil layer. The food coloring is water soluble allowing for the food coloring to dissolve into the water, giving the blue color in Figure (2) below. Once the water was dyed blue, a series of blue food coloring drops were then inserted into the oil layer with no particular quantity. Due to the water-soluble nature, the droplets remained intact within the oil layer. By shaking the toothpick in the oil layer, the blue dye attached to the surface of the oil and stuck until the forces of gravity overcame the surface tension forces. The physics of the phenomena is discussed in depth in a later section. The camera was approximately 12 inches away from the front facing side of the fish tank. An artificial light with settings of full "white" light and full "yellow" light was placed approximately 12 inches away from the tank to the right. The light was level with the height of the tank and angled 45 degrees to the right. Specific lumens of the light were not recorded. All flaps were opened to deflect the light away from direct contact with the tank to prevent unnecessary glare on the glass. The fish tank and camera height were positioned four feet off the ground.

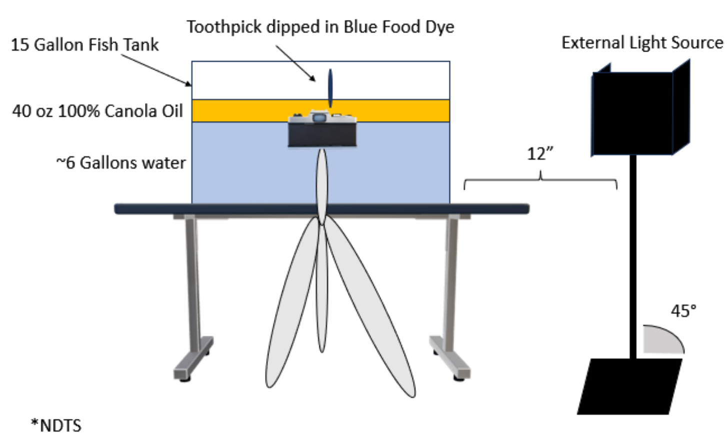

Figure 1: Experimental Diagram Set Up

The set up mentioned above produced the original, unedited image seen in Figure (2). The size of this image is 6016 x 4016 pixels for a file size of 32.3 MB.

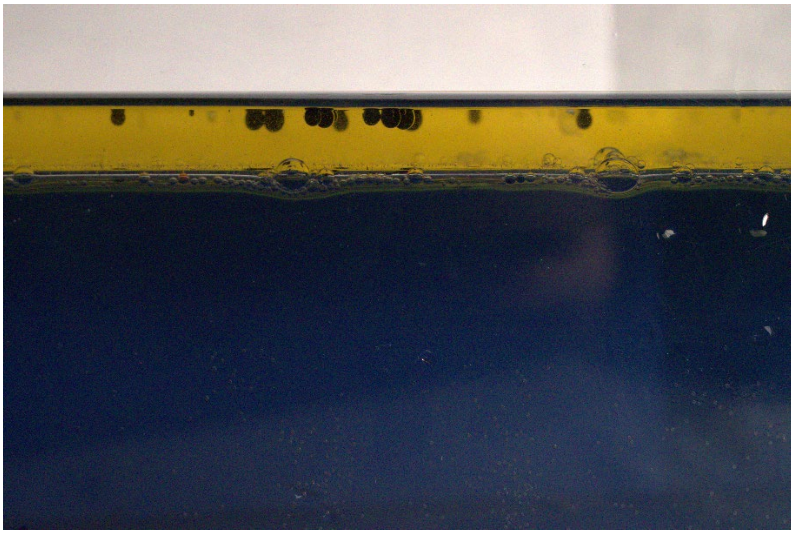

Figure 2: Original, Unedited Image

Table (1) below indicates the parameters recorded from the camera for the capture of the image. The spatial resolution for this image was on an order of 1. This image is considered time resolved indicating that, from one frame to the next, the camera settings allowed for a moment's capture of the fluid phenomena occurring in the image. The droplets appear stationary in the image while compared to images taken slightly before and after the original photo.

Table 1: Image Characteristics

Camera	Nikon D5500
Lens	Nikkor 18-55 mm 1:3.5-5.6G DX VR
Focal Length	40 mm
Aperture	f/7.1
Shutter speed	1/800
ISO	6400
Other	Manual focus

Image Editing Process

Darktable, an editing software program, edited the photo from Figure (2) to get the resulting image seen in Figure (3) below. This image was first cropped and compressed to 3419 x 2123 pixels for a file size of 11.7 MB. I chose this cropping selection to remove the glare from the fish tank on the photo and to bring closer attention to the physics in the image, the water-soluble dye droplets suspended in the cooking oil boundary layer. The first editing step in Darktable adjusted the RGB curve to darken the overall coloring which eliminated the graininess from the high ISO of the original image. The RGB alterations also created a higher contrast in the image which I thought was artistically unique to show the layer of bubbles lying right on the surface between the oil and the water. The second step increased the blue-yellow contrast colors to the right at a value of 5.0 in order to maintain the original coloring of the photo to the best possible extent.

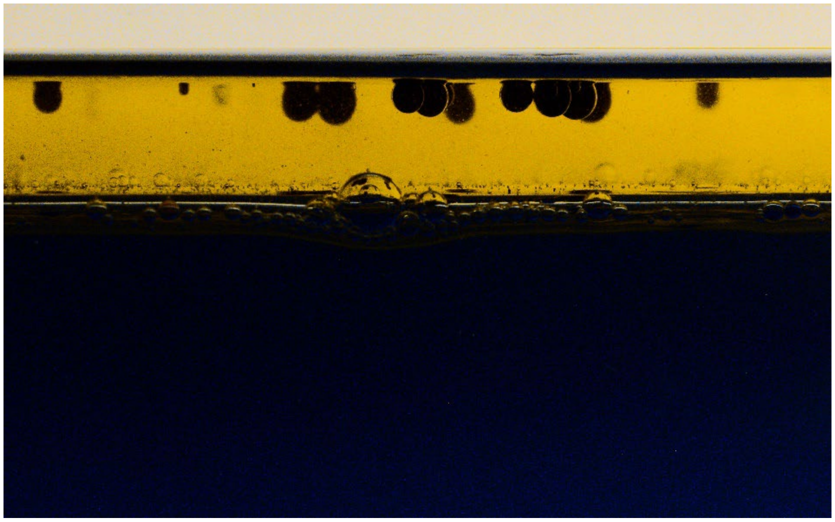

Figure 3: Final, Edited Image

Fluid Flow Phenomena

The Eötvös Number, also known as the Bond number, is a dimensionless number that measures the relationship between the gravitational forces compared to the surface tension forces. (de Haas, n.d.)

$$Eo = \frac{\Delta \rho g L^2}{\gamma} \qquad \text{Eq. (1)}$$

where Δρ = difference in density of the two phases (kg/m^3)
g = force of gravity (m/s^2)
L = characteristic length (m)
ϒ = surface tension (N/m)

The density of canola oil is 0.915 g/cm^3 (Eskin & Przybylski, 2003). The density of food coloring is 1.22 g/cm^3 (Density of Gel Food Color, n.d.). The characteristic length is typically the radius of the curvature of a droplet, so in this case the average length is approximately .0025 m, for the droplet in main focus within Figure (3). The surface tension value used for canola oil is 34.15 mN/m (Zdziennicka, Szymczyk, Jańczuk, Longwic, & Sander, 2019). With the proper conversion of units, the following solves for the Eötvös Number from Equation (1):

$$Eo = \frac{\left(\frac{1220kg}{m^3} - \frac{915kg}{m^3}\right) * 9.81\frac{m}{s^2} * (0.0025m)^2}{.03415\frac{N}{m}} = 0.548$$

One may suspect that the droplet will naturally fall due to the differences in density between the food coloring and the canola oil; however, this experiment demonstrated a method to counter that theory. A bond number less than one indicates that the surface tension forces dominate over the forces of gravity.

(Roth, 2018) The size of the droplet complimented with the force of gravity is not strong enough to pull the droplet downwards and into the water layer below. Instead, the food coloring droplet remains separated the adhered to the surface of the canola oil boundary layer.

A study, analyzing the relationship of an oil droplet shape on a hydrophilic surface due to a critical Eötvös number, found that a “reduction in oil water tension procures a ‘relaxation’ of the drop shape” (Chatterjee, Shape analysis based critical Eotvos numbers for buoyancy induced partial detachment of oil drops from hydrophilic surfaces, 2002). Additionally, this study quantitatively supported that with a low Eötvös number, the higher the interfacial tension is required to maintain a spherical shape of a droplet. There also is a critical Eötvös number that proves the existence of a critical interfacial tension value in order to maintain the drop volume constraint of the experiment; at this critical point the drop shape deviates from the original shape. However, by lowering the interfacial tension force beyond the critical point causes a deviation to the droplet size in too large of a magnitude, likely due to the forces of gravity, to meet the drop volume constraint of the study, making the results of the study incomparable to analyze. (Chatterjee, Shape analysis based critical Eotvos numbers for buoyancy induced partial detachment of oil drops from hydrophilic surfaces, 2002) It can be assumed that the interfacial tension force applies for the surface tension force analyzed in this experiment which generated the image for this report.

Studying the science behind the relationship between oil droplets and a hydrophilic surface is beneficial to the overall science community and the specific interactions between two fluids of different densities. Removing oil drops from a substrate is necessary for oil recovery and detergency, which is the ability to clean a surface. The method of which oil can be removed includes emulsification, which is the process of creating a colloidal suspension of the oil particles in a water based medium; ‘necking’, which is the lowering of the oil-water interfacial tension, driven by the density differences between oil and water, to force the lighter oil drop to detach from the substrate; and ‘roll-up’, which is the reversal of the oils preference to come in contact with a surrounding substrate. (Chatterjee, Critical Eotvos numbers for buoyancy-induced oil drop detachment based on shape analysis, 2002)

Conclusion

I liked the outcome of this photo and found the science behind the phenomena to be unique and an understudied concept. This image clearly shows the science while displaying it in an artistic manner. I dislike the graininess of the image, so, if I were to retake the photo, I would aim to reduce the ISO and increase the lighting source to account for those differences causing the grainy appearance of the photo. The intent of this photo may not have been fulfilled as initially thought, but through further investigation of varying fluid concepts, I think the final image clearly shows the studied Eötvös number for this assignment. In the future, this experiment would be interesting to test the interfacial tensions of different fluids and how those forces interact due to droplet sizing.

Collaboration

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