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MCEN 5051-001

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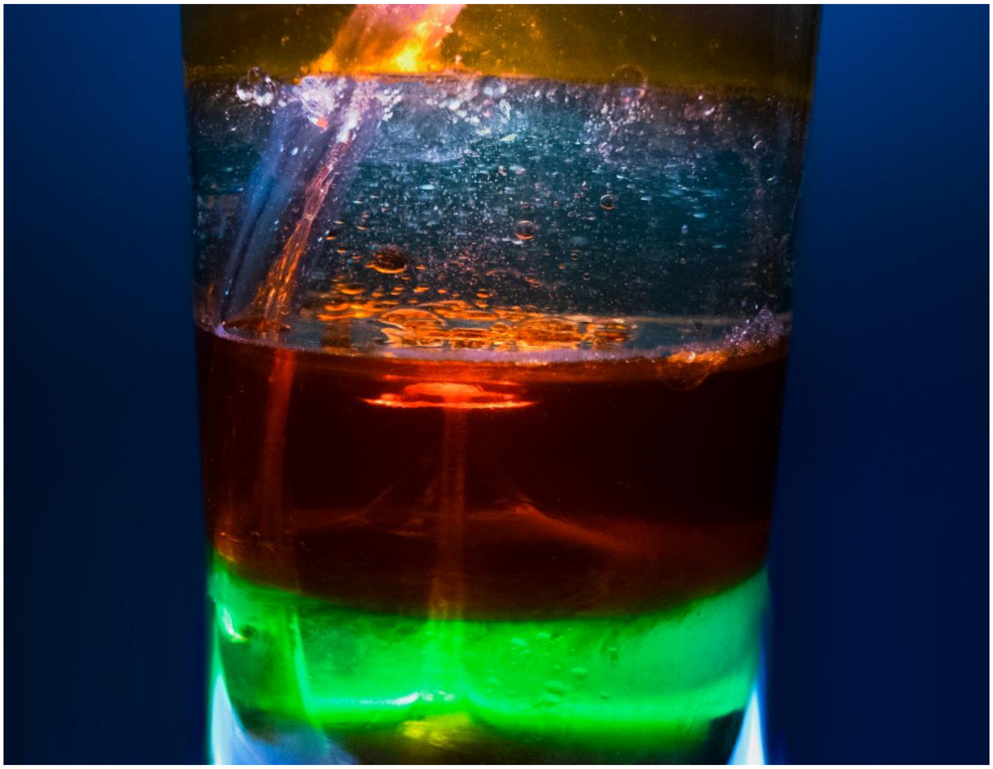
Team First Report



The first team assignment of the semester prompts teams to develop an experiment demonstrating an exciting fluid phenomenon. With the assistance of multiple team members, it is possible to develop a complicated experiment and capture the image with ease. While layering different fluids with varying densities may sound simplistic, the fluids associated with the disturbance of these layers (either through a physical or gaseous means) is quite complex and can produce stunning pictures that match what engineering students only see through a textbook. This image shows an air bubble fighting its way through four separate liquids and clearly demonstrates how settling occurs when there is a disturbance. The four liquids shown in this image are (from bottom to top) green dish soap, water with red flood coloring, vegetable oil (appearing blue due to the background), and isopropyl alcohol. Distortions in the color for the top two layers are due to postprocessing.

Within the image, it is important to note two fluid related principles occurring: the bubble shooting up from the bottom of the image about to breach the vegetable oil layer, and the orange bubbles resting at the bottom of the blue layer. The latter is actually a result of accidental mixing during the experiment setup. As the team attempted to lower liquids into the vase, the vegetable oil clashed with the water layer, causing mixing. Therefore, some of the vegetable oil absorbed the red food coloring from the water and is now resting on the bottom of the vegetable oil layer.

An air bubble released in a medium will rise due to its buoyancy force, which is a function of its size and density [3]. Drag is the opposing force, however it will only slow the motion and does not prevent it from rising [3]. The difficulty in calculating the velocity of the air bubble is the lack of knowledge of the drag force imposed on the rising bubble, although it is usually a function of its Reynolds number. Unfortunately, the Reynolds number is also dependent on velocity, which is what we are eventually trying to find, therefore we rely on experimental results. For sake of simplicity, we will assume the volume and shape of the air bubble is constant. The force on the bubble is calculated through a force balance including buoyancy and drag. The corresponding buoyant and drag forces are shown below,

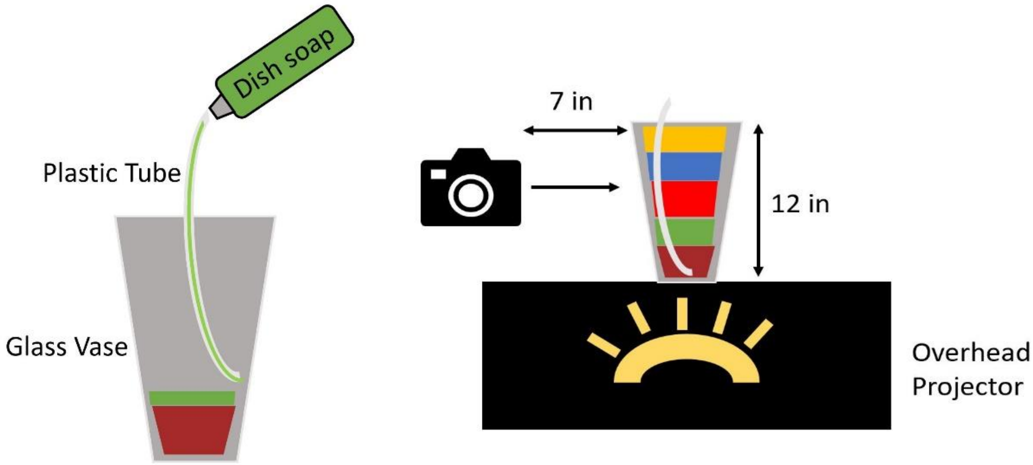
$$F_B = -\rho g \frac{4}{3}\pi R^3 = \left(1.225\frac{kg}{m^3}\right)\left(9.8\frac{m}{s^2}\right)\frac{4\pi}{3}(0.008\,m)^2 = 0.0032\,N \quad [1]$$

$$F_D = C_D Re \frac{\pi}{4}\mu \quad [1]$$

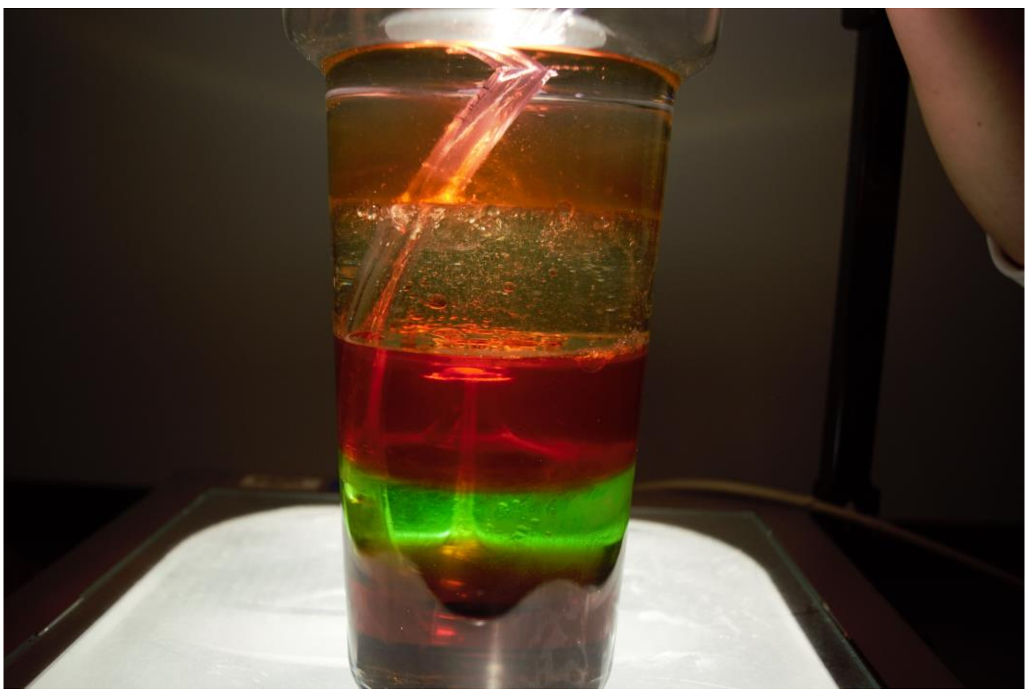
assuming the bubble is a sphere and the density of gas bubbles are neglected. The buoyant force is reasonable because the air bubble has nearly no mass. I did not calculate the coefficient of drag because there is limited literature on drag in fluids of varying viscosity and density. Based on experimental results from previous research studying the velocity of air bubbles in water, we can approximate the coefficient of drag as 1.87 in the water with red dye region [2]. Calculating the bubble velocity as it exits the water layer, we find:

$$v = \sqrt{\frac{8rg(\rho_l - \rho_{g)}}{3\rho_l C_D}} = \sqrt{\frac{8*(0.008\,m)*\left(9.8\frac{m}{s^2}\right)*(1000-1.225)kg/m^3}{3*\left(1000\frac{kg}{m^3}\right)*2.4}} = 0.334\frac{m}{s} \quad [2]$$

As mentioned previously, the team used five layers of liquids (only 4 appear in this picture). From most dense to least dense, the fluids are maple syrup, dish soap, water, vegetable oil, and isopropyl alcohol. It was difficult for the team to carefully lower the liquids to prevent initial mixing, therefore the plastic tubing was introduced and accidentally became a major part of our experiment. The team divided the length of the vase (the fluid housing unit) into five section of equal volume and angled the tube against the side of the vase to slow the speed of the fluid. The vase was then placed on an overhead projector to illuminate the bottom of the vase. We chose to illuminate the bottom to prevent glare on the side of the vase and to watch the light spread throughout the layers. The remainder of the room was dark, and the experiment was completed at night to prevent other light noises from interfering with the experiment. Finally, an air bubble was blown through the tube and rose to the top. The camera was situated 7 inches away from the vase to reduce light on the camera lens. The general setup is shown below including how we lowered liquids in the vase.



As mentioned before, the image was heavily post processed to show contrast in the color of the liquids for aesthetic purposes. The image below shows the original, unedited image. The image was taken with assistance from my other team members: Meg Ivy, Sam Brown, Dawood Ahmad, and Faisal Alismail.



A majority of the image background was cropped to reduce distractions such as the excess light, human arm, and glare in the bottom layer. The image was captured using a Nikon 3300 with the following settings: focal length 20 mm, aperture f/3.8, ISO 800, and a shutter speed of 1/1000 seconds. The original image was 6000 x 4000 pixels, but after cropping the image the final dimensions were 3057 x 2360 pixels. The goal was to focus on the bubbles and boundary layer between the fluids, so I wanted to have a close-up view of how the fluids were interacting. In post processing, I used Photoshop to change the background blue, thus illuminating the vegetable oil in the blue color. I first used the Nikon post processing to add the blue. I shifted the temperature bar as far as possible, which was 2000 in my setting. The temperature setting gives a range from blue to yellow to alter the background, illustrating a cold (blue) feel and a warm (yellow) feel. Moving to Photoshop, not much was manipulated to the vase other than using curves to adjust the output to 236 and input to 213. For the background, I cropped as much as I could to maintain a full image, but the light from the overhead projector was still distracting. I used the blur tool to manually blend the blue into the white light, and it did not turn out as poorly as I thought it would.

After adjusting the image in Photoshop, it speaks more to the separation of layers and how liquids behave with a density gradient. It is now much easier to see the vegetable oil layer and it makes sense why the red bubbles are resting on the bottom of the blue layer. I am curious to find a better way to blend the backgrounds together because that was time consuming and I was worried it would be too noticeable in the image that the blur tool was used, so any comments or suggestions are greatly appreciated. Finally, I would like to investigate a close-up image of the air bubble in a lighter color layer because it seems to be dragging liquids with it as it moves towards the surface.

References:

[1] Manica, R., et al. (2015). Force Balance Model for Bubble Rise, Impact, and Bounce from Solid Surfaces. *American Chemical Society.* 31(24), pp. 6763-6772. Retrieved from https://pubs.acs.org/doi/full/10.1021/acs.langmuir.5b01451

[2] M.Y. Shi et al 2017 IOP Conf. Ser.: Mater. Sci. Eng. 231 012093. Retrieved from https://iopscience.iop.org/article/10.1088/1757-899X/231/1/012093/pdf

[3] Parkinson, L. et al (2008). The terminal rise velocity of 10-100 um diameter bubbles in water. *Journal of Colloid and Interface Science. 322,* pp 168-172. Retrieved from https://reader.elsevier.com/reader/sd/pii/S0021979708001793?token=D45E4372799F9BD9B823FD99A299E7C9AE00105F815075BEEF12C3B79817F1DFA00204070673AB5D08F3F58D7EE43D96