Alyssa Berg

MCEN 5151

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Getting Your Feet Wet

Introduction

For my first initial experiment in Flow Visualization, I chose to observe the phenomenon between oil and water. Initially, I had taken pictures of oil and water being mixed and the bubbles created during the mixing; however in my final picture I added gold quill ink into a container of layered oil and water. I chose to add the gold ink because I thought it would add another dimension fluid flow of the picture and I thought it illustrated the fluid interaction between water and oil better. Ideally, I wanted to show that the water and the oil would remain separate and that the ink acted differently in each medium.

Apparatus

The setup of this experiment was done on the kitchen table in an apartment and a sketch of the apparatus can be seen below in Figure 1.

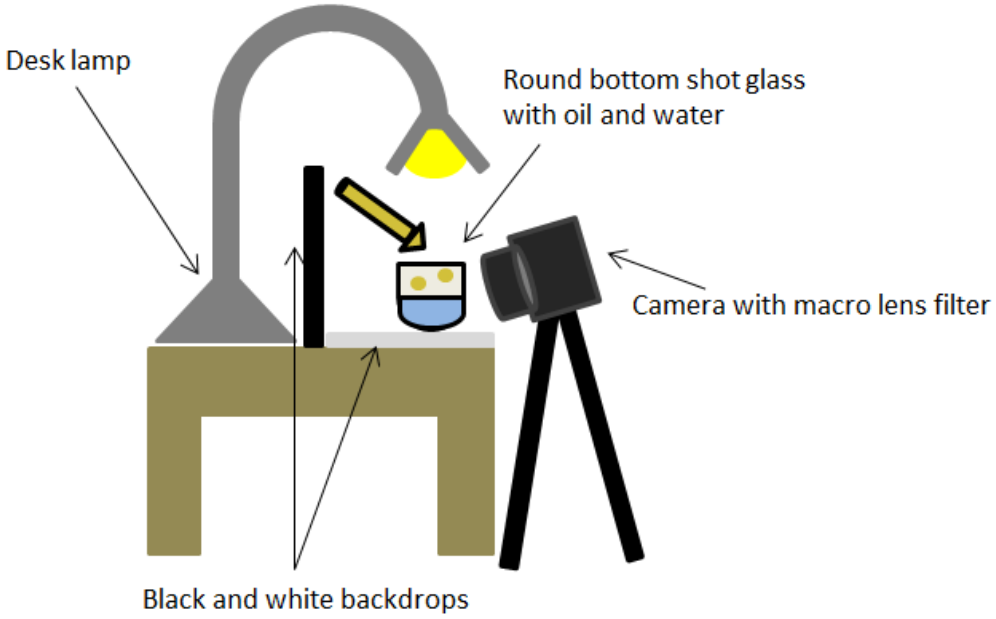


Figure 1: Apparatus

It included a round bottom glass shot glass that is about three inches tall and two inches wide, that holds about four ounces of fluid. It was then filled about a third of the way full of tap water and then another few ounces of vegetable oil were added. The oil and water were left to settle for a minute as to not have any bubbles in the picture. The camera lens was then placed five inches away from the shot glass at angle of 45 degrees. There was also a desk lamp with a 60 watt light bulb that was used as a light source and was placed a foot above the shot glass. Also to avoid glare from surrounding light sources, black construction paper was propped up to surround the shot glass on all sides and was placed six inches away; as well as having a piece of white printer paper underneath, to avoid seeing the grain of the kitchen table. The gold ink was purchased at an art supply company and the brand was Windsor and Newton. The ink was added to the mediums by dropping it from a syringe an inch above the water level. The opening of the syringe was approximately 1/32 inches wide and the droplets were added at a speed of about 3 drops per second to the solution. The final image was captured when some droplets had been added to the solution and they had dropped through the oil into the water below.

Physics behind the Image

The main focus of this picture was to demonstrate the physics and fluid flow between oil and water. The forces that act on the ink when it is dropped into the shot glass include surface tension, gravity, and hydrophobic forces from the oil. When the ink was initially added to the oil it formed spheres out of the ink then they slowly fell to the bottom of the oil. When enough of the spheres pooled at the bottom, they fell through to the water. Then immediately after entering the water, the spheres burst and began mixing with the water. The water and the oil naturally separate due to their different densities. Water has a density of 1.00 g/cm^3 and vegetable oil is .91 g/cm^3 at room temperature [1]. This helps cause the water to sink down and the oil to rise above the water. However the main reason why oil and water separate is due to a hydrophobic effect, where water is a polar molecule and vegetable oil is a non-polar molecule. This hydrophobic effect is not an attractive force between nonpolar molecules nor is it a repulsive force. It is mainly an entropic effect, which results from disrupting the hydrogen bonds between molecules of liquid water and the nonpolar solute [2]. A purely hydrocarbon molecule, such as oil, is incapable of forming hydrogen bonds with water and thus the hydrogen bonds are disrupted and a salvation shell is formed [3]. There is also unfavorable free energy created that is directly proportional to the number of carbon-hydrogen bonds in the hydrocarbon molecule [4]. The nonpolar molecules will then reduce their surface area exposed to water, in order, to minimize their disruptive effect. From this entropy effect between polar and nonpolar molecules the water and oil separated to reduce their surface area. This is also the reason why the ink formed small spheres when it entered the oil. A sphere has the best ratio of surface area to volume of any object. This also explains why the sphere burst open when they entered the water.

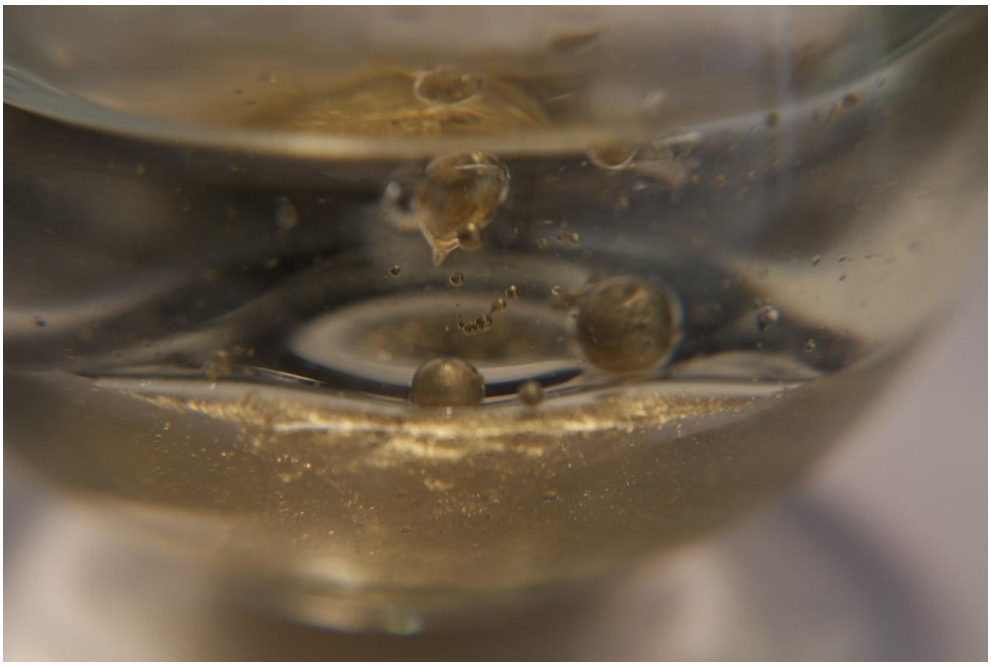
Another force that acted on the ink was the surface tension. Surface tension is often represented by γ and for water at room temperature the value is 71.97 mN m^{-1} [5]. Surface tension is defined as the force along a line of unit length, where the force is parallel to the surface but it remains perpendicular to the line [6]. In the center of each droplet before it entered the water, the molecules are pulled in every direction creating a zero force. However on the surface the molecules are not pulled equally on all sides and they are pulled inwards [6]. This creates internal pressure and forces the liquid to contract to

minimal surface area. However when a pool of droplets settles on the bottom of the oil and the weight of the ink began to increase the force from the surface tension became too weak and the droplets sank from the oil to the water and they burst. Overall, the main forces that were seen in this picture were a hydrophobic force, surface tension, and weight from gravity. However in this experiment, Reynolds number and Grashof number were zero initially since neither one of the fluids were moving and didn't significantly relate to this experiment.

Image Specifications

The field of view in the final picture is one inch wide and about two inches tall. The picture was taken five inches away at an angle of 45 degrees. The picture is 4045 pixels in width and is 2996 pixels in height. The focal length of the lens was 50 mm and there was also a macro lens filter on the lens. The image was taken with a Cannon EOS 7D camera with the flash turned off. The shutter speed of the image was 1/80 seconds and the aperture value was f/5.0. The ISO value was set to 500. The faster shutter speed was used to capture the separation of the ink in the oil; this also made it more challenging to capture a picture that was in focus. The macro lens filter was also used to be able to capture the small separations of the ink and to give the picture a more artistic feel. Photoshop was used on the rendering of the final picture; the specific program I used was Aperture for mac. I mainly increased the contrast between the colors as well as the saturation, as well as the brightness was increased slightly. I also used a specific sharpener to sharpen the small droplets in the middle of the picture, because I wanted that to be the focus of the picture. I also used vignette, which is a technique of blurring the edges and making it more focused in the center, since this would increase the viewer's focus on the smaller droplets in the center. The raw picture is included and can be seen in Figure 2 and the final picture after editing can be seen in Figure 3.

Figure 2: Unedited Picture



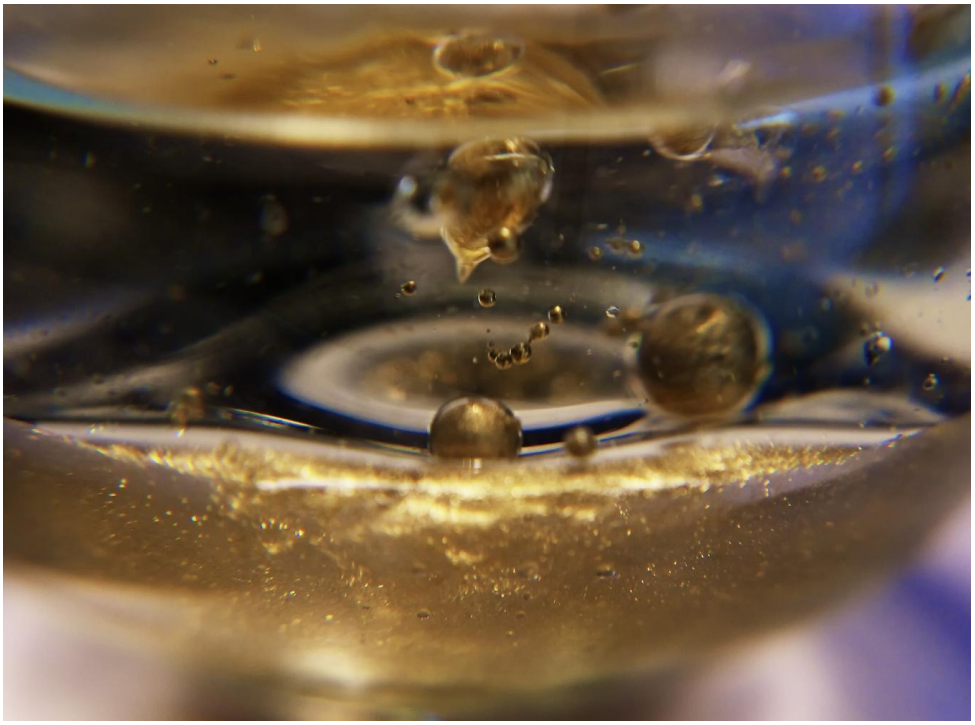


Figure 3: Edited Picture

Conclusion

This image reveals the interaction between water and oil and was more clearly illustrated through the use of quill ink. The part that set this picture apart from other ones I took was the smaller droplets in the middle of the picture and they are clearly the focus of the picture as well as my favorite part. The physics are shown pretty well in this picture. This is shown in the oil section when the ink forms into balls because of the oils hydrophobic forces and then it also shows that the balls settle on the top of the layer of water and then gravity pulls the down further and then they are released from their spherical shape when they come in contact with the water. Something I would like to investigate would be to see the different reactions of several fluids besides quill ink. An example that would be interesting to look at could be a fluid that would mix with oil, but doesn't mix in water, such as dyed olive oil, dyed vegetable oil, or dish soap. This picture illustrates the physics fairly well; however something that was pointed out during the critiques was that the background may appear distracting and there is a slight glare from the glass. If I were to redo this picture I would pick a different backdrop as well as better light to avoid these distractions. Overall, I really like my picture and I am proud that I learned quite a bit about photography and how important seemingly small items such as lighting can be to a picture.

References

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