Get Wet

MCEN 5151

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This experiment was designed to explore the interactions between oil, water, and food coloring. The problem that was faced was how these three substances should be mixed together. Several attempts were made at just mixing different types of food coloring with water and observing the effects. The results were quite predictable and somewhat uninteresting. This is when vegetable oil was added to the picture. It is generally known that oil and water do not mix due to "London forces." The intent of this image was to get a first taste of experimenting with fluids. The final image shows the viscous forces and Rayleigh-Taylor instability in play between the carbonated water and food coloring, as well as the separation of hydrophobic oil and water. The use of oil created a time release effect for the dye entering the club soda. Originally, I was not sure what to expect, but after researching the topic more thoroughly, I could have demonstrated the desired phenomenon more clearly.

The subject of interest, dye, was introduced by being mixed first with the oil. Since the dye is water based, it has a density of 1 g/mL whereas the density of vegetable oil is roughly .915 g/mL. The greater density of the dye causes it to move through the oil to the water and then be released. The diameter of the glass was about 4 inches, with the height of the water also being 4 inches. Since the image was not captured immediately after the oil/dye mixture was introduced into the glass, there is overwhelming presence of the turbulence between the dye and water. The value for the Reynolds Number dictates the motion of the droplet and what formations will be observed. By definition, the Reynolds Number is a dimensionless parameter defined by the ratio of dynamic pressure and shearing stress.[1] The Reynolds number is calculated by the equation:

$$R_e = \frac{\rho V L}{\mu}$$

Using the parameters from the experiment: density of water 1 kg/L, speed of dye roughly 10 cm/s, diameter of glass 6 inches, and dynamic viscosity of water at room temperature 1 kg/m-s, we find that:

$$R_e = \frac{1\left(\frac{kg}{L}\right)*10\left(\frac{cm}{s}\right)*6(in)}{1\left(\frac{kg}{m*s}\right)} = 15.2$$

Note: The above values were converted to proper units to produce a dimensionless parameter.

A droplet that is introduced to a fluid under the force of gravity deforms into a torus that eventually becomes unstable.[2] Once the torus becomes unstable, it breaks into some type of secondary shape. This shape is correlated to the Reynolds number. Lower Reynolds numbers produce fewer offshoots of secondary drops. As the Reynolds number increases, the unstable torus forms into more complex and bag-shaped formations. With Re = 15.2, we would not expect there to be a great amount of bad-shaped instability.

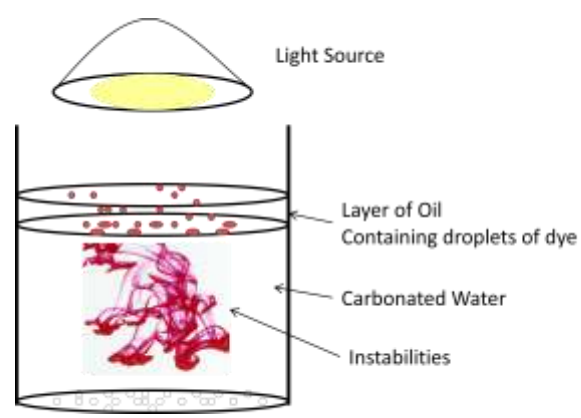

Figure 1: Flow Apparatus: Created using Powerpoint

The apparatus above is a general sketch of the setup used to create and observe suspension drops. The temperature of the water used affects the dynamic viscosity. As the temperature of the water increases, the viscosity decreases causing the dye to mix faster. The inverse is true in that as the temperature becomes colder, the mixing occurs slower.

Another phenomenon common with these types of experiments is the formation of vortex rings. While the image produced does not capture any clear vortex rings, they occur frequently when a single droplet of dye is dropped from a given height into still water falling under the force of gravity. Along with the height, the liquid into which the dye is dropped affects the distance to which the dye travels before creating a vortex ring. The main source of energy in creating vortex rings is derived from the surface energy of the drop which is almost twice the potential energy of the drop.[3] As the velocity of the drop decreases as it moves through the fluid, the diameter of the drop increases. Eventually a ring is formed for some short period of time before it dissipates.

To better illustrate the flow of this image, red dye was used. First, club soda was poured into a clear glass. Roughly six drops of red food coloring were then stirred thoroughly into about 1.5 ounces of vegetable oil. The mixture was then completely poured into the club soda. After some time, the food coloring sank through the oil and dispersed into the club soda. To capture this event, a desk lamp was used to light the glass directly from above. A photo tent was not used, so some ambient light was unavoidable. A stronger light source would have allowed for a brighter image, but one was not available at the time. To prevent reflection from the glass, a flash was not used when the picture was taken.

The original field of view captured the entire width of the glass. The width of the glass was about four inches across, and club soda was roughly four inches high inside of the glass. The original image size was 3872x2592 pixels at 300 dots per inch (dpi). The final image was cropped to show greater detail and to eliminate slight glare off of one side of the glass. The final digital image is roughly two inches wide by three inches tall (1837x2163 pixels). The total distance from the object to the lenses was roughly 18 inches with the focal length set to 37.5 mm. The image was taken in low light conditions so the exposure had to be carefully chosen. The first value that was set was the aperture. With the focal length set to 37.5 mm, the smallest aperture that could be obtained was f/4.5. The fluid image did not require great depth of field, so this aperture setting allowed for the most possible light to be let into the camera for any given period of time. With average lighting, I chose an ISO value of 400 and set the shutter speed to 1/15 of a second. While a higher ISO could have been used to obtain a quicker shutter speed, it would have resulted in a grainier image that I wanted to avoid. To eliminate any blur that may have been caused from shaking hands, the camera was mounted on a tripod. The camera used was a DSLR Pentax K2000. This camera was set to set shoot in raw (DNG) format with a resolution of 10.2 MP. The large resolution of the original allowed for a small cropped portion of the image to still have sufficient resolution.

There was ample post-processing done on the original image using Photoshop. First, the original was cropped down to its final size. This allowed for greater detail to be seen, but it also eliminated some glare off of the glass. Next, the contrast and color content were changed using the curves tool. The image contained a narrow range of predominantly red and green. There was some blue towards the lower end of the spectrum but this was removed to further enhance the reddening effect of the dye. Initially, some of the edges of the dye flow were not sharply defined. To enhance these edges, a duplicate layer was created and a high pass filter was applied to it. The blend mode of this layer was set to overlay which provided the desired effect of more defined edges.

The image reveals the turbulent flow of dye mixing with club soda. What I really like about the photo is the slow and gradual release of dye from the oil into the club soda. The oil sits on top and is soft and out of focus, but since it is not the main point of the image I think it works very well. Unfortunately, the fluid physics are not demonstrated incredibly well. Each droplet of dye that enters the club soda is quite small as well as scattered. The surface tension of the carbonated bubbles at the bottom of the glass can clearly be seen. I did fulfill my intent of observing the turbulence present when mixing two fluids of the same density. With better lighting, I believe a better image could have been obtained and different effects could have been observed as well. This could be expanded to test how temperature affects the same interaction. Also, does the color of the dye affect the rate at which it disperses throughout the club soda? How much does the carbonation affect the physics of the dye? It would be interesting to try this experiment again with various solvents dissolved into the water and observing how it affects the dye. One aspect that could be changed would be to get all of the dye to release simultaneously from the oil, creating a more uniform image. This would allow for greater comparison across the whole image. My final image shows dye streams in all different states, some just beginning and others having no definite shape or demonstration of fluid physics. Overall, as my first endeavor with fluid dynamics in any way, I'm fairly satisfied with the final image that was produced.

REFERNCES

[1] "Reynolds number." *Encyclopædia Britannica. Encyclopædia Britannica Online*. Encyclopædia Britannica, 2011. Web. 09 Feb. 2011. <http://www.britannica.com/EBchecked/topic/500844/Reynolds-number>.

[2] Bosse, Thorston, Leonhard Kleiser, Carlos Hartel, and Eckart Meiburg. "Numerical Simulation of Finite Reynolds Number Suspension Drops Settling Under Gravity." *Physics of Fluid* 17.037101 (2005). Print.

[3] Chapman, DS and Critchlow, and PR. "Formation of Vortex Rings from Falling Drops."*Journal of Fluid Mechanics* 29 (1967): 177-85. Print.