Cold Coffee Creamer in Hot Coffee

Get Wet

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MCEN 4151

Flow Visualization: The Physics and Art of Fluid Flow

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Background

The purpose of the Get Wet image is to capture a fluid, or combination of fluids, to understand the physics of the flow in the experiment. The experiment must be controlled so it can be repeated. In this experiment, I wanted to examine the mixing of two different fluids. The two fluids had different viscosities and different temperatures.

Setup

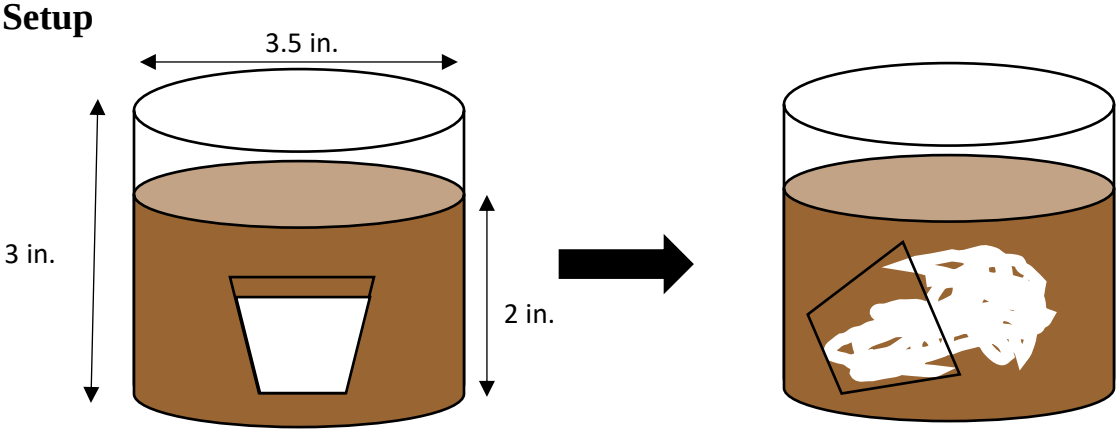

Figure 1: Experiment setup showing the two different stages of the experiment.

Figure 1 depicts the two different stages of my experiment. To begin, 2 inches of hot coffee was poured into a glass with a diameter of 3.5 inches and a depth of 3 inches. Next, a standard shot glass (1.5 fl. Oz.) with cold coffee creamer was lowered into the coffee. Because of the difference in densities, the creamer stays inside the shot glass without mixing with the coffee. The camera was then set up about two feet away from the front of the glass. After starting the video, the shot glass was then tipped over in the coffee.

Fluid Dynamics

Reynolds Number

The Reynolds Number is a dimensionless value that measures the ratio of inertial forces to viscous forces and describes the degree of laminar or turbulent flow [1]. If the glass is modeled as a pipe, we can determine whether the flow of the creamer is laminar or turbulent. If Re is greater than 4000, the flow is turbulent, otherwise, the flow is laminar.

To calculate Reynolds Number, we need the velocity of the creamer. For the creamer to travel the full two inches of the coffee from top to bottom, it took 124 frames of the video. I was shooting the video at 240 frames per second, which equates to the following:

$$v = \frac{d}{t} = \frac{2\ inches}{\frac{124}{240}\frac{frames}{fps}} = \frac{2\ inches}{0.5166\ seconds} = 3.871\frac{in}{s} = \ 0.098\ \frac{m}{s}$$

Given that $v = 0.098\frac{m}{s}$, $\rho = 8.47\frac{oz}{cup} = 1014.9\frac{kg}{m^3}$ [2], $\mu = 0.0071\frac{kg}{m*s}$ [2], and $L = 2\ in. = 0.0508\ meters$, we can calculate the Reynolds Number of the creamer.

$$Re = \frac{\rho v L}{\mu} = \frac{1014.9\left[\frac{kg}{m^3}\right] * 0.098\left[\frac{m}{s}\right] * 0.0508\ [m]}{0.0071\left[\frac{kg}{m*s}\right]} = \frac{5.0826\ [m]}{0.0071\ [m]} = 711.63$$

With a Reynolds Number less than 4000, we can determine that laminar flow is occurring if we model the glass as a pipe. The flow of the creamer doesn't appear laminar in the video, so this model might not be the best to determine the type of flow occurring in this experiment. The flow of the creamer isn't flowing from the top to the bottom of the glass, but rather from the middle of the glass outward toward the top and bottom.

Visualization Technique

The Rayleigh-Taylor instability is an instability of an interface between two fluids of different densities [3]. This occurs when the lighter fluid pushes on the heavier fluid. In this case, the submerged fluid is denser than the fluid above it. This can be seen in Figure 2 when the creamer and coffee don't mix unless a force is imparted on the shot glass.

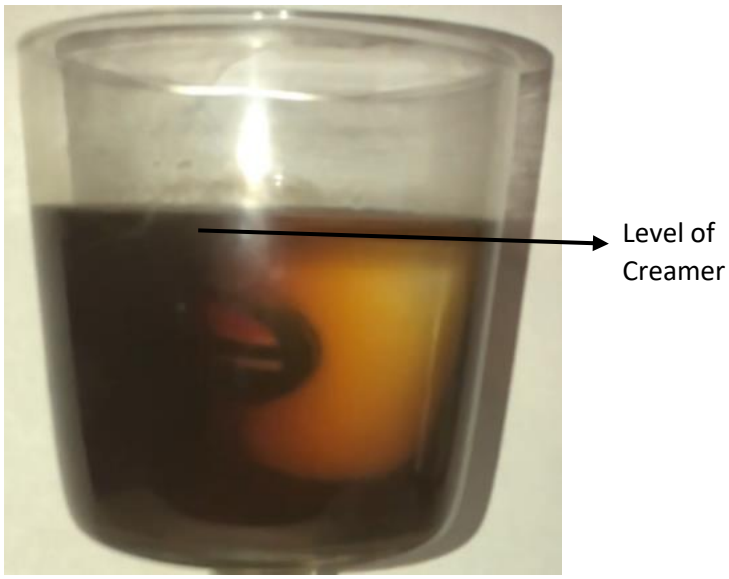

Figure 2: Rayleigh-Taylor instability in cold creamer and hot coffee

Photographic Technique

To see what was happening in slow motion, I used my iPhone 8 Plus camera filming at 1080p and 240 frames per second. This allowed me to see what was happening every 1/240th of a second. Initially I used a frame from the video as my image for this project, but the focus that I had was slightly out of whack and didn't like the edit that I made in Photoshop (see Figure 3).

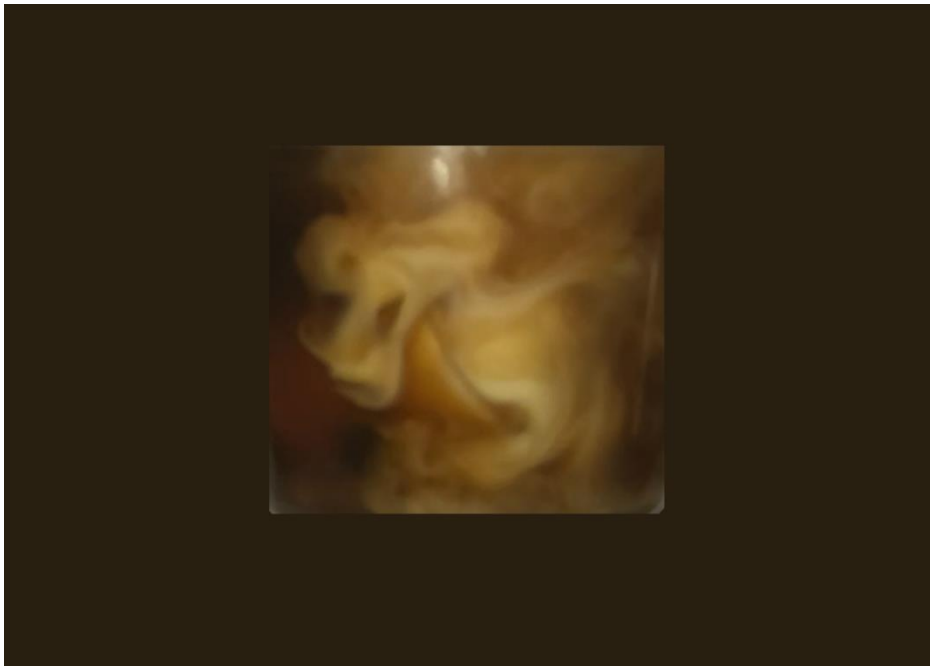

Figure 3: Original edited image for Get Wet assignment.

Conclusion

With the Rayleigh-Taylor instability shown excellently in my video, I believe that my experiment was a success. If I were to do it over again, I could use magnets to tip over the shot glass instead of my finger, which could have caused disturbances in the surface of the coffee, changing the way that the creamer interacted with it. Using a semi-high-speed video to visualize this flow was certainly more effective than the original image submitted. Overall, I am happy with the way I was able to visualize the interaction between creamer and coffee.

References

[1] “Reynolds Number.” NASA, Glenn Research Center, www.grc.nasa.gov/www/BGH/reynolds.html.

[2] "Viscosity of Foods." Viscosity of Foods., www.engineeringtoolbox.com/absolute-viscosity-foods-d_1827.html.

[3] "Rayleigh-Taylor Instability." Hydraulique Et Mécanique Des Fluides., hmf.enseeiht.fr/travaux/CD0001/travaux/optmfn/hi/01pa/hyb72/rt/rt.htm#begin.