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Flow Visualization 5151-002

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Team First | Nostalgic Rain

In the pursuit of developing comprehensive knowledge regarding the small whispers of decaying foam that roll through my morning brew, I revisited the flow of my Get Wet project with the aid of my teammate. This revision placed an emphasis on capturing the phenomenon in higher resolution; to fill the screen with precise framing. The experimental process also revealed the key attributes that produce the desired flow, enabling greater reproduction rates.

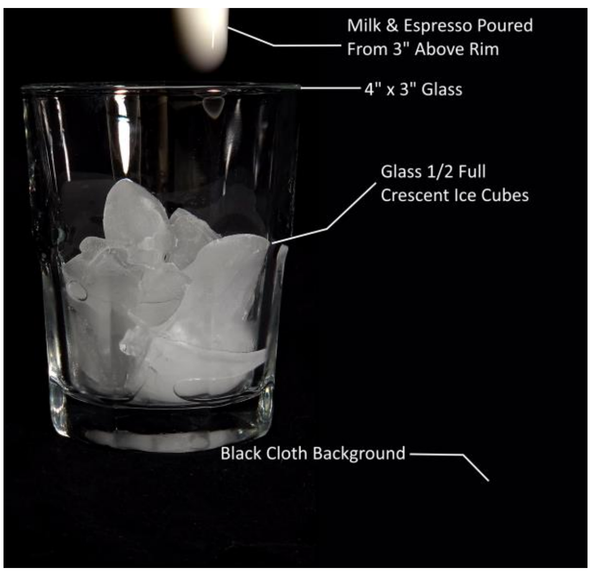


Figure 1: View of scene from camera with descriptions of setup

Figure 2: View of scene from above, illustrating distance from lens to glass

Just as in the get wet project, a room temperature 250 ml glass with high transparency and minimal features was filled just under halfway with crescent shaped ice cubes. 50 ml of 4 °C creamer, Chobani Sweet Cream, was combined with 150 ml of whole milk, at the same temperature, and frothed in a Keurig Standalone Frother on the cold setting. 28 ml of espresso was prepared from whole beans, brewed at 8bar for 29 seconds, giving a firm crema at a temperature of 90 °C. The frothed product was added to the glass 8 cm above the top of the glass and sat for six seconds. The espresso was microwaved on high for 10 seconds to bring the liquid to 97°C and then was immediately added 8 cm above the top of the foam, directly in the center of the glass. Dron Das Purkayastha was then able to record the shot on his camera while I also recorded with my cell phone.

Revisiting the flow, I found that the effect only occurs after the initial mixing of espresso and milk has reached a steady state in which there is no visible movement within the glass; the foam settles at the top, and coffee / milk mixture is at rest at the bottom. I believe that the driving force of the flow can be attributed to the Rayleigh-Taylor Instability within the frame of a low Reynolds number flow.

The Rayleigh-Taylor Instability occurs when a denser fluid flows down through a less dense fluid. To determine if the conditions apply, a density must be found for the three ingredients. To determine the density of the creamer, I refer to a 1962 Research Article by P.D. Watson and R.P. Tittsler in which an equation for cream density was derived from milk fat percentage and I independently calculate the density by measuring the mass and volume of a parcel of creamer: I believe the density of the creamer to be 1.15 g/ml. The density of the coffee I pull from a paper "The experimental data on the density, viscosity, and boiling temperature of the coffee extract" published by A P Khomyakov, S V Mordanov and T V Khomyakova, from the department of chemical plant machinery and equipment, Institute of Chemical Engineering, Ural Federal University, Ekaterinburg, Russia. Extracting figures based on a high temperature, high dry substance mass fraction datapoint, I believe the density of the espresso to be 1.19 g/ml. The density of whole milk was found to be 1.03 g/ml from a 2020 NIH publication (P Parmar et al., 2020).

Considering that the stabilized foam is primarily creamer, and the coffee-milk mixture is primarily milk, it can be concluded that the relatively higher density creamer is suspended above the relatively lower density milk-coffee mixture via a microbubble foam. As the foam decays, the microbubbles collapse, and droplets of creamer are formed and fall through the glass. The tendrils of creamer present as long whisps instead of vortices due to the low Reynolds number of the flow:

$$Re = \frac{\rho u L}{\mu} = \frac{1150\,\frac{kg}{m^3} * 0.002\,\frac{m}{s} * 0.016m}{40\, mPa \cdot s} = .00092$$

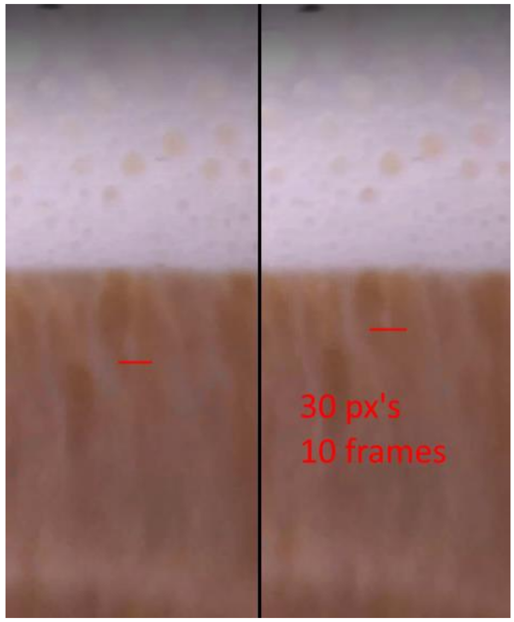
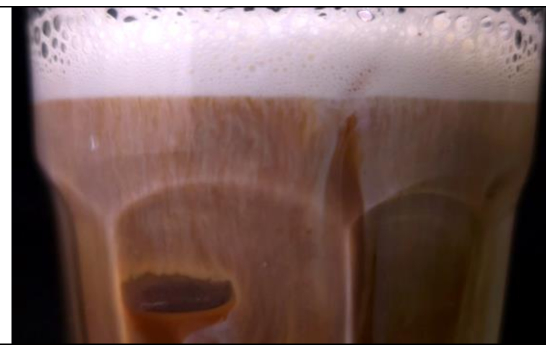


Figure 3: Measuring a single whisp's movement

The speed and length of the flow was determined from two screenshots, 10 frames apart, accounting for the 2x speed editing of the flow, the viscosity was brought from an engineering approximate viscosities resource. The actual figure is relatively negligible in the face of the very slow and short flow. The resultant Reynolds number then indicates that the flow should be laminar and explains the smooth Raleigh-Taylor Instability.

Similar to the methods of visualization used in the Get Wet experiment, the only controlled aspects of the scene were lighting and background: no alterations were made to the fluid itself to enhance visibility. The background was selected as a black fluid tolerant tablecloth that could withstand a spill without altering the appearance of the fabric, steamed and hung such that it produced no creases that may be visible in the final filming. In this iteration the fabric was placed such that the backdrop was wider, enabling off center shooting. Dron was responsible for most of the lighting, the scene was recorded in the long hours of the evening such that no external light came through windows; the only sources of light were 5500 K spotlight bulbs diffused with white fabric. The color temperature was selected to be neutral between warm and cool colors. One spotlight was aimed such that it minimized glare on the glass, set 45 degrees off the line between the camera and the glass at a distance of 22" from the glass. The other spotlights were directly above the glass at 34".

The raw video itself was shot at 7680x4320 at 30 frames per second on a Samsung S24+; the quality was the highest available to me with a set framerate. I utilized my phone's telephoto, 3x optical zoom, lens with a F/2.4 aperture and a 67mm focal length. The video was recorded at a distance of 10cm from the glass with the intention of maximizing the detail of the flow, with a field of view of 4.5”x2.5”. I started with minimizing the ISO to its lowest setting, 50, in an attempt to reduce noise in my dark background. I then set the shutter speed to 1/60 to achieve the exposure I desired. In the editing of the video, I was able maintain 4K resolution with my upgraded subscription to Microsoft Clipchamp, but I still lost some of the resolution I gained by recording in 8K. I chose to only increase the contrast and saturation of the clip by a few points to give the background an inky black appearance against the beverage. I enjoy the visual feeling of the glass existing alone in space, I feel that it helps focus the mind on the flow at hand. The video was sped up by a factor of two for all clips to better illustrate the relatively slow movement of the flow.

Before	After
	

Considering the second iteration of this experiment, I find myself rather happy with the improvements that I made the perspective that I gained. For all the same artistic reasons, I am happy with the coloring and the contrast in the visuals. I am now even more happy with the story that the video tells within a complete focus on the flow. I found that I got my greatest clarity still with my telephoto lens but moved the camera much closer to focus on the most interesting component. There were many shots that I took that were out of focus, whenever I am shooting in the future, I will manually focus my image and not rely so heavily on the autofocus. There were very beautiful moments that were lost to this error. I am pleased that I set a strong direction for myself in the last report, and I was able to fulfil my goals here in this experiment.

References

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