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Assignment 3 Report
ARTF 5200
Assisted by Leah Selman

Bad Water Rising

12/03/2021

Overview

This picture was taken with the intent to visualize the Raleigh-Taylor instability. Specifically, the two fluids used were chilled water and hot water, the latter of which also contained red food coloring. Leah Selman assisted in the set up of the photograph, and extruded the hot water.

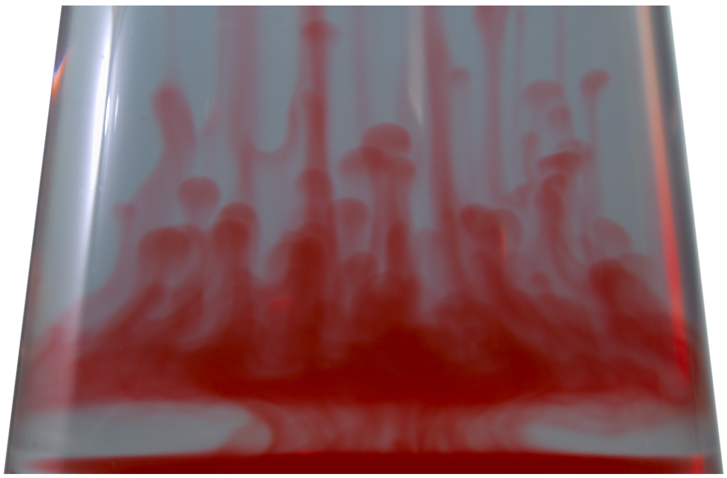

Figure 1: Finalized version of the picture taken, after post processing. The size of this image has also been reduced for display purposes.

The Flow

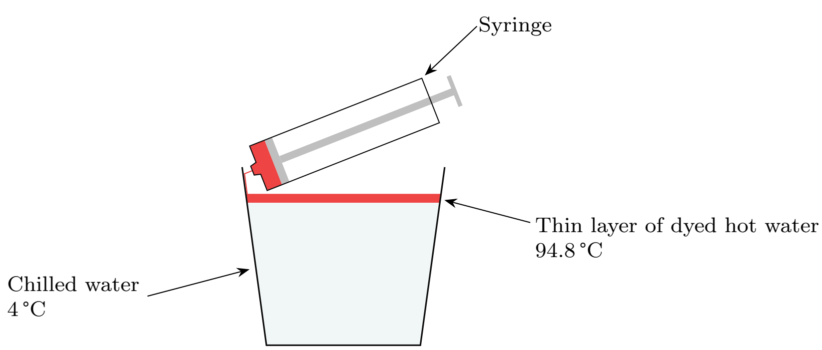

Figure 2: Diagram of the experimental set up.

First, the cold and hot fluids were prepared. To create the *cold fluid*, cold tap water was placed into a refrigerator in order to chill it. Next, a mixture of red food coloring and water was microwaved to create the *hot fluid*. When the *hot fluid* was ready, a small translucent glass was filled with the *cold fluid*, and a small amount of the *hot fluid* was drawn into a syringe. The *hot fluid* was then deposited on top of the chilled water as carefully as possible. It is helpful to direct the syringe towards one side of the glass, as is illustrated in Fig. (2). This allows the *hot fluid* to contact the *cold fluid* at a reduced velocity, which will prevent premature mixing of the two fluids. The instability did not become noticeable until 1-2 minutes had passed. The final image was captured 3-4 minutes after the *hot fluid* had been placed.

Prior to characterization of the flow, we first consider in what situations the Rayleigh-Taylor instability occurs. Explained both elegantly and succinctly by Wieland *et al.*, the "Rayleigh-Tayor instability (RTI) arises when there is a mean density gradient in the direction opposite that of an acceleration" [1]. As such, the Atwood number, defined in Eq. (1), is a dimensionless parameter that has a significant impact on the behavior of an RTI. Here, ρ_1 is the density of the heavier fluid, and ρ_2 is the density of the lighter fluid.

$$A = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} \tag{1}$$

Prior to calculating anything, however, we must first determine the properties of the relevant fluids. In order to approximate the temperature of the *cold fluid*, we will assume that it achieved a steady state while in the refrigerator. The average temperature inside a refrigerator is 4 °C [3], so we will assume that the *cold fluid* has an initial temperature of 4 °C. Although the *hot fluid* was not yet boiling, it was relatively close, meaning that using the average boiling point of water as the *hot fluid's* initial temperature is a reasonable assumption. The boiling point of water in Boulder, Colorado is approximately 94.8 °C [4, 5]. From these initial temperatures, we can approximate properties of our two fluids, which can be seen in Table 1.

Table 1: Relevant properties of the hot and cold fluids [6]

Property	**Hot Fluid**	**Cold Fluid**
Temperature (°C)	94.8	4
Density ($\mathrm{kg\,m^{-3}}$)	962.03	999.95

The initial density values would imply that the Rayleigh-Taylor instability should not occur. This is accurate, however, as the instability did not begin to form until to temperatures of the two different fluids approached a similar value. Once the temperatures of the two fluids is sufficiently close, the *hot fluid* will actually have a slightly greater density than the *cold fluid* do to the food coloring present in the hot fluid. At this point, we have achieved a situation in which an RTI will form, and the Atwood number will be approximately zero. As time progresses, the Atwood number will slowly increase.

Visualization Techniques

In the image, the *hot fluid* is primarily water, dyed with red food coloring for both a visual and functional purpose. Prior to the placing the *hot fluid* on top of the *cold fluid*, the cup was placed on top of a white piece of paper, which was in front of a white posterboard. Relative locations and orientation of light sources, can be seen in Fig. (3). This set up was chosen in order to create a neutral background with sufficient light.

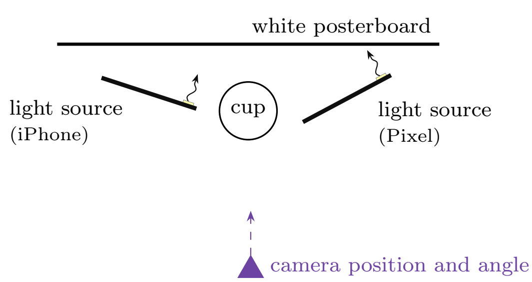

Figure 3: Birds eye view diagram of light setup including approximate location of camera lens during shooting. Diagram is not necessarily to scale.

Photographic Techniques

The pictures were taken with a Nikon D90 using an AF-S DX VR Zoom-Nikkor lens. An aperture of f/5.6, an exposure of 1/15, an ISO of 159 were used. The original image, in lower resolution, can be seen in Fig (4) for context regarding initial image quality and field of view. Post processing for the photo primarily took place in Darktable, followed by cropping and conversion to portable networks graphic (PNG) in GIMP. Post-processing consisted primarily of lens correction, adjusting white balance, modifying color curves, and increasing local contrast. The decision to crop the image down was made in order to remove the background, which I felt was not necessary in the final image. The image was also rotated 180°. The final image is seen in Fig. (1).

Figure 4: This was the original photo taken, unedited other than to reduce it's size for display purposes. The original image was 4310×2868 pixels.

Final Thoughts

I am overall very pleased with the final outcome of this photo. In particular, the image is sharp, and the colors were brought out with post processing such that the intricacies of the flow are more apparent. One aspect of the phenomenon that is particularly interesting is the stem-like section near the bottom of the final image. I believe that this happened because the surface of the water heated up faster than the deeper water, meaning that two fluids reached a similar temperature faster. If I were to repeat this kind of visualization, I would create a *hot fluid* with a more saturated color, and potentially even use immiscible fluids. The Primary concern here would be that the densities of these two materials would have to be close enough such that the temperature difference process used here would still work.

References

[1] S. Wieland, S. Reckinger, P. E. Hamlington, and D. Livescu, "Effects of background stratification on the compressible Rayleigh Taylor instability," 47th AIAA Fluid Dynamics Conference, 2017.

[2] D. H. Sharp, "An overview of Rayleigh-Taylor instability," Physica D: Nonlinear Phenomena, vol. 12, no. 1-3, pp. 3–18, 1984.

[3] Office of the Commisioner, "Are you storing food safely?," U.S. Food and Drug Administration. Available: https://www.fda.gov/consumers/consumer-updates/are-you-storing-food-safely.

[4] "ThermoCalc," The Boiling Point of Water Calculator. Available: https://www.thermoworks.com/bpcalc/.

[5] "Local weather forecast, news and Conditions," Weather Underground. Available: https://www.wunderground.com/.

[6] "Water - density, specific weight and thermal expansion coefficients," Engineering ToolBox. Available: https://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html.

NOTE: academic literature used are citation numbers 1 and 2.