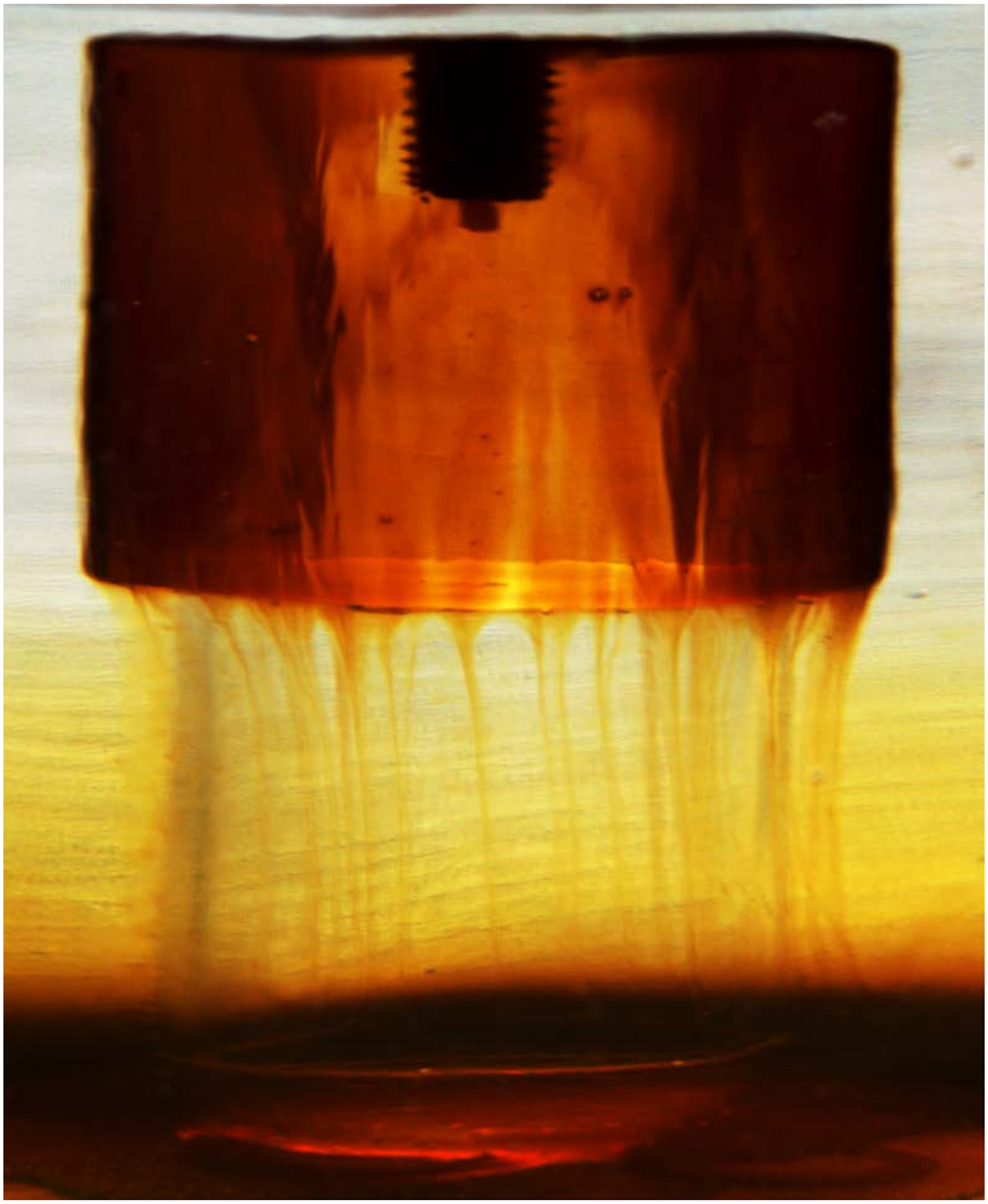
Team Second



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Purpose

The purpose behind this experiment was to capture a photograph of an interesting fluid phenomenon in an artful but enlightening way for Professor Jean Hertzberg's Flow Visualization class at the University of Colorado at Boulder in the Fall of 2015. The specific goal for this project was to play with density variations between water and molasses flowing over objects immersed in the water. The hope is that the end result should make the objects almost disappear by choosing objects with similar indices of refraction to water. This project was done in conjunction with Kelsea Anderson, Sam Ballard, and Haleigh Cook.

Experimental Setup

The experimental setup to generate this image was actually quite simple. To begin a container roughly 2" in radius and 4" tall was filled with water at ground water temperature (approximately 55 degrees Fahrenheit). This was then placed outdoors in front of a white backdrop. Then the first of the two cylinders was placed gently into the center of the container. This cylinder was hollow and approximately .75" in radius and 1" tall. Then the second cylinder, which was solid, was placed on top of the first. The second cylinder was roughly 1" in radius and 1" tall. Also, the second cylinder had a machine threading in the center of the top of it. From there, approximately 2-3 teaspoons of room temperature (about 60 degrees Fahrenheit) blackstrap molasses was deposited onto the top of the second cylinder. This was then allowed to flow off of the cylinder and into the bottom of the container. At this point the photo was taken. Figure 1 shows a diagram of the setup used.

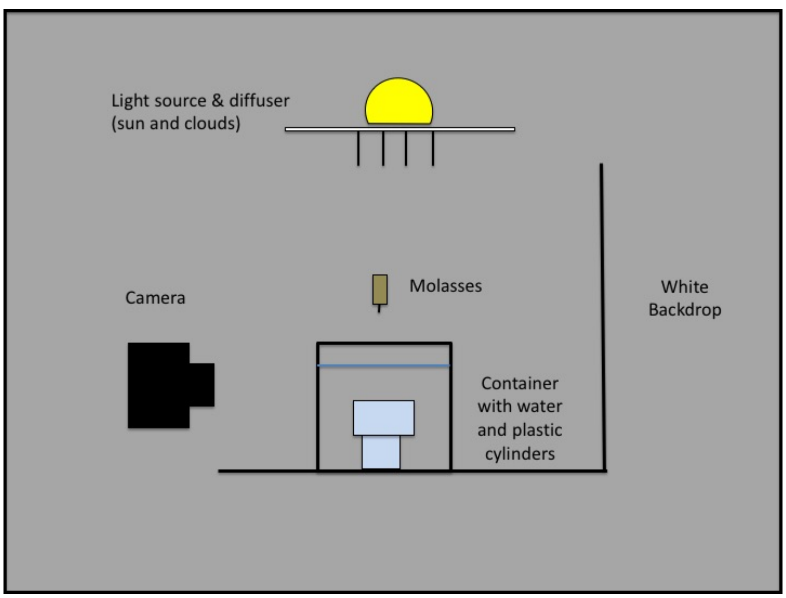

Figure 1: The experimental setup used for the photograph

Fluid Physics

After depositing the molasses onto the upper cylinder, the molasses begins flowing outward along the surface of the cylinder. Upon reaching the edge of the cylinder, the molasses stays close to the cylinder walls in a thin layer as it flows downwards. Upon reaching the end of the upper cylinder, the thin sheet of molasses then has the opportunity to flow freely to the bottom of the container. This thin sheet of molasses creates an interface between the molasses and the water that results in a nearly two dimensional Rayleigh Taylor instability (RTI)). The RTI is an instability that results from having a density difference across an interface between two fluids. The requirement is that this change in density is in the opposite direction of some accelerative force, i.e. we have a more dense fluid above a less dense fluid in the presence of gravity. In this case, the more dense fluid is the molasses and the less dense fluid is the water. Finally, to develop an RTI, some perturbation needs to be applied to the interface between the two fluids. This interface had its perturbation generated by the non-uniformity of the flow coming down the cylinder walls (Sharp, 1984).

The defining characteristics of a RTI are the development of bubbles, the light fluid rising into the heavy fluid, and spikes, the heavy fluid descending into the light fluid. Essentially, when the perturbation is applied, the RTI causes the growth of this perturbation. Initially, the original sinusoidal perturbation will grow linearly in amplitude, but then it will begin accelerating and growing exponentially. At this point, the complex bubbles and spikes will soon develop because, as the perturbation grows, vorticity is generated either in a vortex ring (3D) or in vortex pairs (2D) which leads to the self propagation of the flow. As they continue growing, the cross sectional area of the bubble begins to enlarge while the cross sectional area of the spike becomes smaller, leading to the two regions to look as their respective names suggest, i.e. the bubble becomes large and rounded, while the spike becomes skinny and pointed (Daly, 1967; Sharp, 1984).

There are two non-dimensional numbers that really categorize an RTI, namely the Reynolds number, and the Atwood number. The Reynolds number, as usual, serves as a measure of the viscous effects of the system with higher Reynolds numbers equating to lower viscous dissipation. In this case, we have molasses with a high viscosity moving very slowly equating to the Reynolds number being quite low. Without having a way to measure the velocity of the fluid, it is difficult to estimate the Reynolds number, but since the molasses appears to be almost in a creeping flow regime, we can estimate that the Reynolds number is at most on the order of 1, but is potentially even lower. The Atwood number is a relationship between the densities of the two fluids, namely it is the ratio between the difference of the two densities and the sum of the two densities. The molasses used has a specific gravity of about 1.5 while the water used has a specific gravity of 1.0. This equates to an Atwood number of 0.2, which is a moderate value (Daly, 1967; Sharp, 1984).

Combining a low Reynolds number and a moderate Atwood number together in a nearly two dimensional flow equates to a couple of features. The first feature this leads to is a large difference in bubble and spike shape. This can be easily seen by the fact that the bubbles are large and rounded while the spikes are very long and appear as skinny fingers that reach into the bottom of the domain. Secondly, this combination leads to the flow being very laminar and this can be seen by the fact that the RTI is able to continue in a single mode with no additional modes developing. If these other modes developed it would be seen by the interaction of vorticity causing the bubble and spike formations to break apart or combine in any number of unpredictable ways. Finally, it is common for RTI to develop Kelvin-Helmholtz instabilities along the fluid interface, but at low Reynolds number and higher Atwood numbers this interaction is suppressed. In this specific case, the Kelvin-Helmholtz instability is so suppressed that it appears non-existent (Daly, 1967; Sharp, 1984).

Photographic Technique

The photograph was taken using a Nikon D3300 with a Nikkor 18-55mm lens. The ISO was set to 100, the shutter speed to 1/30 of a second, the f value 10, and the focal length to 55mm. The resolution of the original image was 4000x6000 pixels. All of these specifications provided ample resolution for such a slow moving flow. The camera was approximately 1 foot away from the subject, and the picture was taken outside to make use of the ample amount of sunlight available to us. In post-processing the image was rotated and cropped to be 3168x3861 pixels, and then the curves tool in GIMP was utilized in order to increase the contrast. The original and final images can be seen in Figure 2 for comparisons sake.

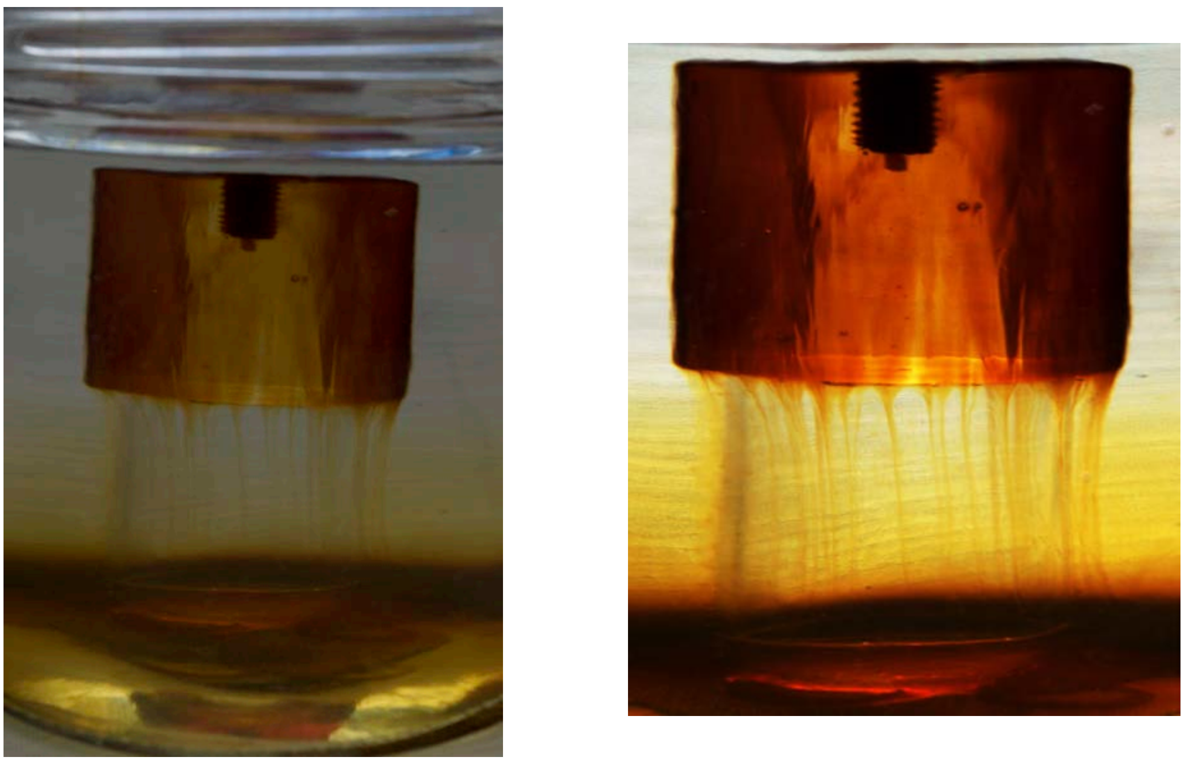

Figure 2: A comparison between the original and the edited images.

Conclusion

In the end, I was successfully able to capture an interesting flow phenomenon that resulted in the formation of Rayleigh Taylor instabilities. The final image was well resolved and aesthetically pleasing, and shows ample detail of the flow. Based on estimates of the non-dimensional parameters of interest, the flow physics seen exhibit behavior that is predicted by the literature. The final product was able to fully realize my intent and the equipment I was able to use was of good enough quality that it did not hinder the process. The only modification I would consider is to replace the backdrop with a more solid white backdrop without any visible patterns in it, but I've actually grown to like the slightly patterned backdrop.

Bibliography

Daly, B. J. (1967). Numerical Study of Two Fluid Rayleigh-Taylor Instability. *Physics of Fluids*, *10*(2), 297. doi:10.1063/1.1762109

Sharp, D. H. (1984). An overview of Rayleigh-Taylor instability. *Physica D: Nonlinear Phenomena*, *12*(1), 3–18. Retrieved from http://www.sciencedirect.com/science/article/pii/0167278984905104