

Rayleigh-Taylor Instability and the Hydrophobic Effect

Red Wine Vinegar and Extra Virgin Olive Oil

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Image Context

For Get Wet 1, Rayleigh-Taylor instability and hydrophobic phase separation were visualized using common household items: a shot glass, a reading lamp, extra virgin olive oil, and red wine vinegar. The intent of this image was to reveal the hydrophobic property of oil and its role in phase segregation as well as to demonstrate Rayleigh-Taylor instability, “a fluid phenomena arising from a dense fluid above a lower density fluid in a gravitational field.” [1] In other words, when a dense fluid (in the case of this experiment a liquid) is placed on top another less-dense fluid, instability in the flow and mixing occurs. The result of these phenomena is an opportunity to capture interesting and beautiful images.

Experimental Apparatus and Flow Characteristics

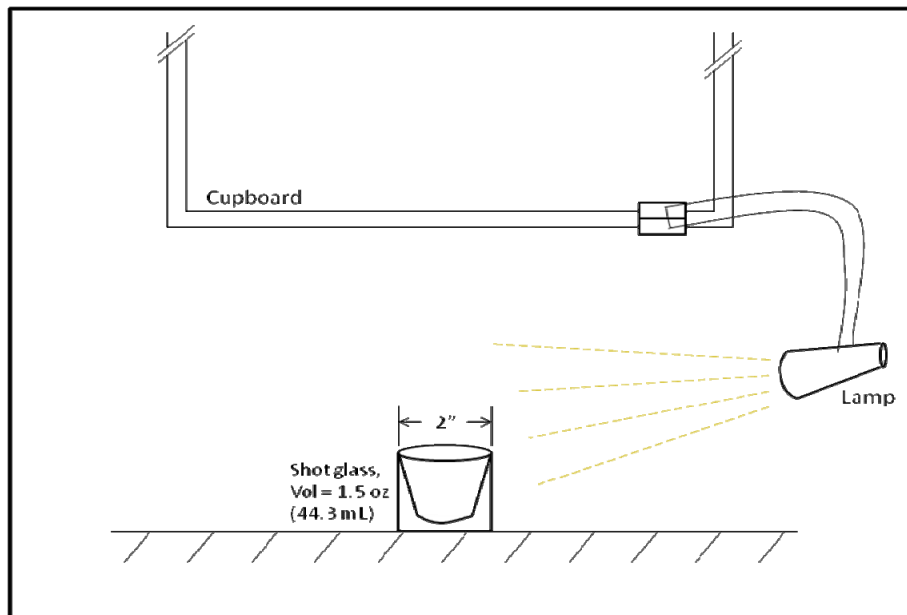


Figure 1. Sketch of Experimental Apparatus

Figure 1 illustrates the experimental apparatus used to render the image, which is nothing more than common household and kitchen items. A standard, clear 2" (0.025 m) diameter, 1.5 oz shot glass housed the extra virgin olive oil and red wine vinegar. The shot glass first contained only 0.75 oz (roughly half the shot glass) olive oil, the less-dense fluid, and an equal volume of red wine vinegar, the dense fluid, was poured into the shot glass with the photograph taken seconds later [2]. A reading lamp was clamped to the bottom shelf of the cupboard to variable-angle light source.

The flow depicted in the photograph is two-fold: Rayleigh-Taylor instability and the hydrophobic segregation of an oil and aqueous phase (red wine vinegar). Rayleigh-Taylor instability results from the dense fluid displacing the less-dense fluid due to its larger body force (from the acceleration due to gravity). Moreover, there is phase separation between oil and aqueous phases due to the hydrophobic

property of olive oil. Oils are made up of long carbon chains that tend to mix with other long carbon chain molecules. On the other hand, water and acetic acid (together they are called vinegar) are relatively small molecules with strong polarity due to electron localization around more electronegative atoms, namely oxygen. The result of the polar-non-polar interaction is phase separation, sometimes called the hydrophobic effect. The hydrophobic effect is essential to the formation of cell walls in all living organisms and many other biological processes. Since there is no net flow of fluid in or out of the shot glass (our “system”) after the vinegar is poured in, the most appropriate characteristic dimensionless number that describes the phenomena is the Atwood number (A). The formula is shown below in Equation 1 (ρ_1 refers to the heavier fluid; ρ_2 refers to the lighter fluid).

$$A = (\rho_1 - \rho_2) / (\rho_1 + \rho_2) \quad (1)$$

The Atwood number is density ratio used commonly in the study of Rayleigh-Taylor instability for density-separated flows, much like the system used in the experiment used to generate the photograph on the title page [3]. For this system, the Atwood number is 0.045, meaning that the fluids are of similar density but enough different for clear phase separation to occur.

Visualization and Photographic Technique

To visualize the Rayleigh-Taylor instability and phase separation, different colored liquids (light-yellow oil and red vinegar) allowed the phase separation to be observed clearly. A high angle spotlight was generated using a common bedside reading lamp. This light produced the shadow and striking differences in color seen in the final image. A Canon EOS Digital Rebel with shutter speed set to 30, aperture to f/5.6, ISO sensitivity to 400, and focal length of 90 mm produced the image with a field of view roughly 3 inches. The image was processed in Adobe Photoshop CS4 to improve the contrast with the “Curves...” function; the dark areas were made darker, the light areas lighter.

The Final Image

Inspection of the image reveals some interesting and beautiful fluid dynamics happening. The phases are nearly fully separated and only within seconds of the vinegar being added to the oil indicating the speed with which these processes can occur. A clear phase boundary has already formed on the left half of the mixture with the more dynamic Rayleigh-Taylor instability captured in the right half of the glass. What I like about this image is the orderly phase separation between the vinegar and oil juxtaposed with the instable flow all in one small 1.5 oz shot glass. I dislike the yellowish lighting, had it been available, I would like to have used a cleaner, whiter light source. To develop this idea of Rayleigh-Taylor instability further, a more orderly apparatus could be utilized. For instance, an eye dropper or micropipette could be used to inject the vinegar into the oil and really make the instability pop. Overall I am pleased with the final product and look forward to capturing more and more interesting flow phenomena.

References

- [1] A.R. Pritz, O. C. (2006). The Rayleigh-Taylor Instability. *American Journal of Physics* , 1095-1098.
- [2] Elert, G. (2000). *The Physics Factbook*. Retrieved 2 2, 2009, from Density of Cooking Oil:
<http://hypertextbook.com/facts/2000/IngaDorfman.shtml>
- [3] J Glimm, J. W. (2001). A critical analysis of Rayleigh-Taylor growth rates. *Journal of Computational Physics* , 652-677.