Get Wet Report

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Introduction

This image captures a close-up view of a hibiscus tea bag steeping in a cup of hot water. Immediately after the tea is added to the water, thin streaks of tea begin to settle towards the bottom of the glass, folding over as they become more turbulent. However, these quickly become indecipherable as the tea color diffuses more into the surrounding water. I intended to capture these falling streaks of tea to display the effects of buoyancy, convection and diffusion within this flow.

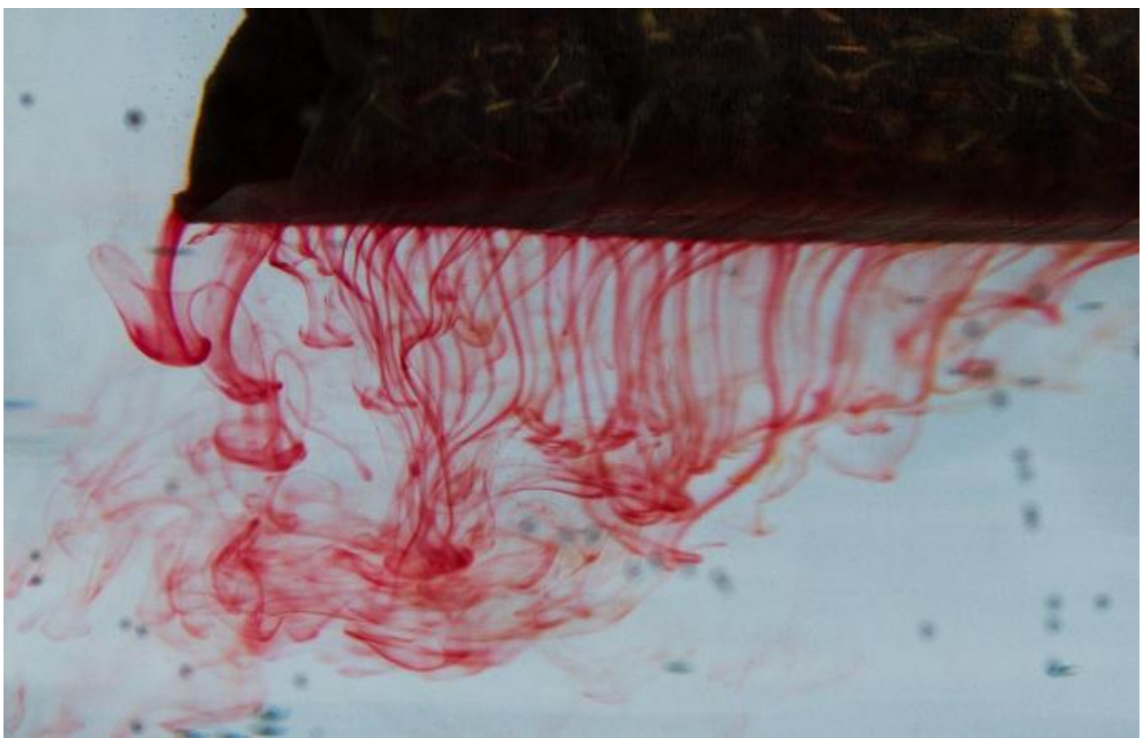

Figure 1: Final Image

Setup

The setup used for this image was quite basic. I used a large piece of paper as a white background and set up my glass next to a brightly lit window. The camera was held by hand about 6-10 inches from the subject and focused manually. The tea bag string was wrapped around a pencil to suspend it near the top of the glass.

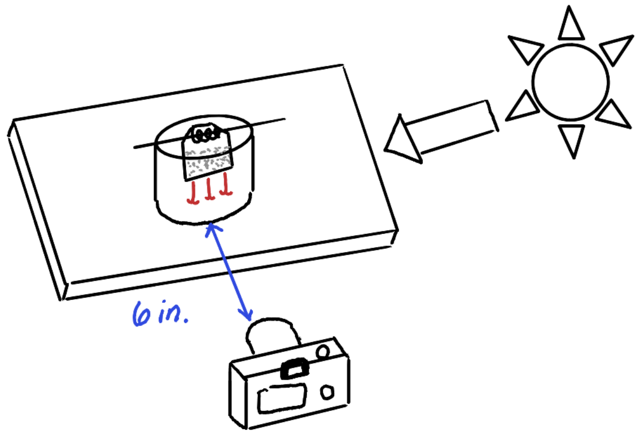

Figure 2: Setup Sketch

Visualization Technique

Hibiscus tea was chosen specifically to utilize the vibrant red color as a natural dye to reveal the flow. Strong natural lighting from the right side of the image was used. Using a large window with direct sunlight allowed me more flexibility with the camera settings.

Photographic Technique

A Nikon D3000 DSLR camera with an 18-55mm 1:3.5-5.6 lens was used to capture this image. Being a standard lens, the far end of the focal length (55mm) was used to zoom in as close as possible to the tea bag. This shot, taken from about 6-10 inches away, nearly fills the frame with the glass. A medium aperture size f/9 was chosen to maximize the light input, without sacrificing too much depth of field. The shutter speed was set to 1/320 to get a crisp shot of the fluid while in motion. Finally, the ISO was set to the lowest setting of 100. Since there was plenty of light in the setup, I didn't see any need to increase it.

Darktable was used to process the final image. It was cropped from its original size (3900 x 2613 pixels) to remove the edges of the glass from the frame. Additionally, the retouch tool was used to remove a few of the bubbles which stuck to the sides of the glass. Lastly, to adjust the overall contrast, I used curves with individual RGB channels to darken the red tea color, as well as the background. In my opinion, higher contrast makes the final image easier to understand. In the original the tea color appears much less saturated (especially in less concentrated areas) which is harder to distinguish from the light background.

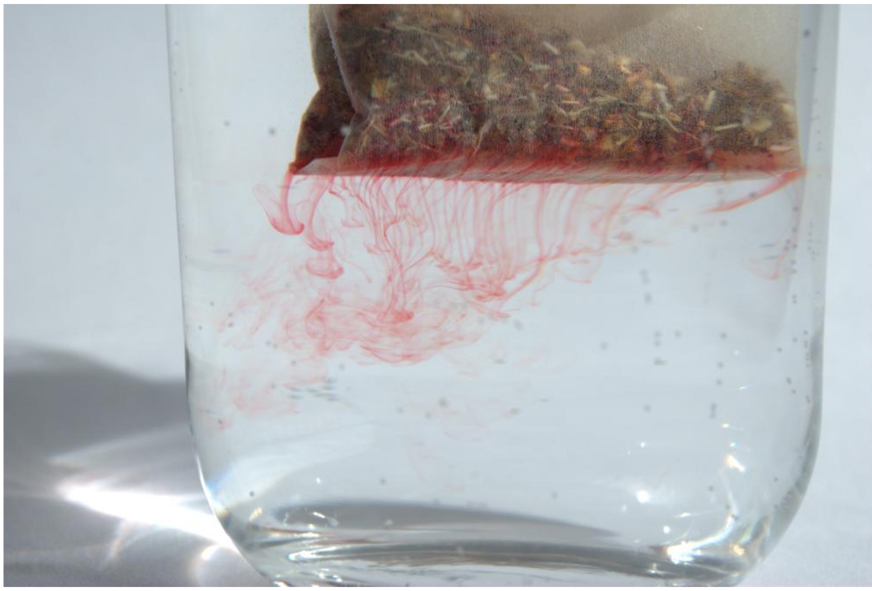

Figure 3: Original Image

Analysis

The flow in this image exemplifies qualities of Rayleigh-Taylor instability, as well as diffusion. A density increase in the dissolved tea causes buoyant forces to push the fluid downward [1]. As this occurs, there is shear along the interface between the tea-dissolved and normal water, which pulls the leading edge of the streak upward [2]. These combined forces tend to create a long thin plume, with a mushroom shaped cap. In this scenario, we have a heavier fluid on top of a lighter one, so the plumes propagate downward. The plumes which I observed were about 1.5-2.0 cm in length and 0.5-1.5 mm in width.

Using some estimations for physical properties, the Solutal Rayleigh number may be calculated as follows:

Assumptions (hot water, near boiling)

$$\begin{aligned} H &= 0.10 \text{ m} && \text{geometric scale, water depth} \\ g &= 9.81 \text{ m s}^{-2} && \text{gravity} \\ \frac{\Delta\rho}{\rho} &= 1.0 \times 10^{-3} && \text{guessed fractional density difference} \\ \nu &= 3.0 \times 10^{-7} \text{ m}^2/\text{s} && \text{kinematic viscosity, hot water} \\ D &= 1.5 \times 10^{-9} \text{ m}^2/\text{s} && \text{solute diffusivity in hot water} \end{aligned}$$

Definitions

$$\begin{aligned} Ra_s &= \frac{g\,(\Delta\rho/\rho)\,H^3}{\nu\,D} && \text{Solutal Rayleigh number} \\ g' &= g\,(\Delta\rho/\rho) && \text{Reduced gravity} \\ U_b &= \sqrt{g'H} && \text{Buoyancy velocity} \\ T_b &= \sqrt{\tfrac{H}{g'}} && \text{Buoyancy time scale} \end{aligned}$$

Plug-in calculation

$$\begin{aligned} H^3 &= (0.10)^3 = 1.0 \times 10^{-3} \text{ m}^3 \\ \nu D &= (3.0 \times 10^{-7})(1.5 \times 10^{-9}) = 4.5 \times 10^{-16} \text{ m}^4/\text{s}^2 \\ \text{Numerator} &= g(\Delta\rho/\rho)H^3 = 9.81 \times (1.0 \times 10^{-3}) \times (1.0 \times 10^{-3}) = 9.81 \times 10^{-6} \\ Ra_s &= \frac{9.81 \times 10^{-6}}{4.5 \times 10^{-16}} \approx 2.18 \times 10^{10} \end{aligned}$$

Context scales

$$\begin{aligned} g' &= 9.81 \times 10^{-3} \text{ m s}^{-2} \\ U_b &= \sqrt{0.00981 \times 0.10} \approx 3.13 \times 10^{-2} \text{ m s}^{-1} \\ T_b &= \sqrt{\tfrac{0.10}{0.00981}} \approx 3.19 \text{ s} \end{aligned}$$

The solutal Rayleigh number (Ra_s) measures the balance between buoyancy forces, viscosity, and diffusion in a fluid system where solute concentration creates density differences. In the case of steeping tea, dissolved compounds near the tea bag slightly increase the local fluid density compared to the surrounding water. This density difference drives downward plumes under gravity, while viscosity resists motion and diffusion tends to smooth out concentration gradients. A large value of Ra_s (well above the critical threshold of about 10^3) indicates that buoyancy dominates over viscous and diffusive effects, resulting in vigorous convective mixing and the finger-like structures seen in the image. The very high value calculated here (Ra_s ≈ 10^10) confirms that solutal convection, not molecular diffusion, controls the plume growth during steeping.

Reflection

Overall, I'm quite happy with the result. Artistically, it achieves what I wanted it to. From a physics perspective, the fluid phenomenon is not abundantly clear but does nicely explain what is happening in the flow. The image could be improved a lot with a bit of setup work. Adjusting the aperture and focus to increase the sharpness would add a lot of value. If I were to do this again I would also try thickening the fluid, to slow the flow and reduce instabilities.

References

[1] Banerjee, A. (2020). *Rayleigh–Taylor instability: A status review of experimental designs and measurement diagnostics*. Journal of Fluids Engineering, 142(12), 120801. https://doi.org/10.1115/1.4048403

[2] Sharp, D. H. (1984). An overview of Rayleigh–Taylor instability. Physica D: Nonlinear Phenomena, 12(1–3), 3–18. https://doi.org/10.1016/0167-2789(84)90510-4