Blue Descent: Buoyancy-Driven Dye Plume

Iker Acha

Flow Visualization, September 24th, 2025

1. Introduction

This report will detail the experimental setup, visualization techniques as well as flow apparatus and physics behind the image *Blue Descent: Buoyancy-Driven Dye Plume*, submitted for my Flow Visualization "Get Wet" assignment. The goal of this assignment was to devise and execute an individual experiment that revealed both the aesthetics and physics behind fluid motion. My submission's intent was to capture in a clear yet aesthetic way, how buoyancy-driven convection and laminar-to-turbulent flow occur in simple systems.

I initially experimented with dripping food dye directly into a still glass of water. Although the patterns produced were colorful and aesthetic, the flow was too fast and exhibit chaotic dynamics to capture the distinct transitions, which was precisely the aim of this experiment. In order to amend this, I embedded the dye into an ice cube, which slowed down the release of the dye into the water, in turn, generating plumes that evolved over several seconds and could be captured in distinct and clear stages. The setup required for this experiment was carried out using everyday materials in an attempt to highlight how accessible flow visualization can be.

2. Flow Apparatus and Physics

The experiment was performed with a clear cylindrical mason jar approximately 12 cm tall and 6 cm in diameter, filled to the top with tap water at ~21 degrees Celsius. Over many tries, a single ice cube (~3cm edge length) pre-loaded with four drops of blue food dye was placed gently at the water surface level mark so as to minimize potential disturbance of the still water which could affect the flow visualization process. As the cube melted, dyed meltwater descended into the mason jar.

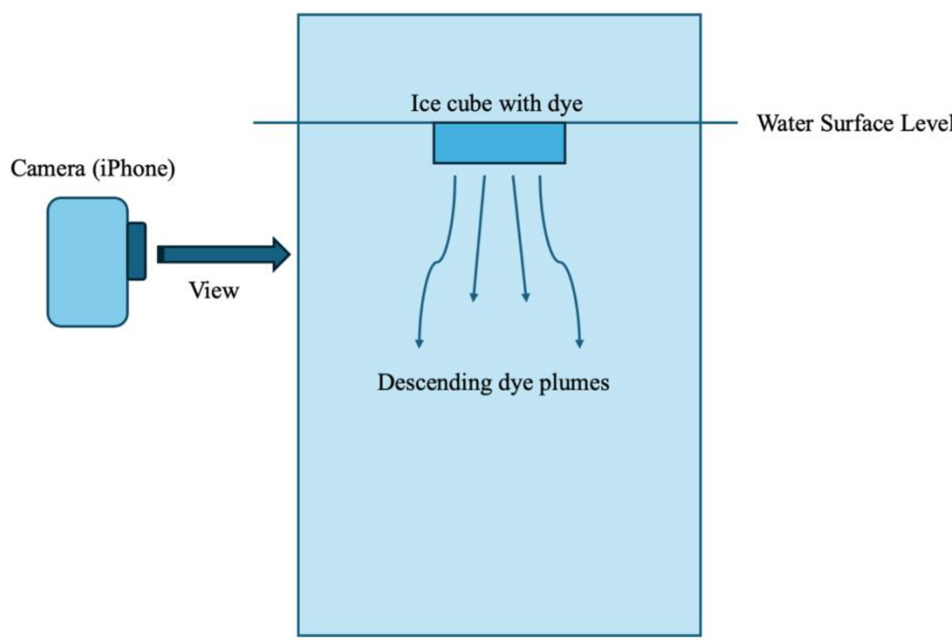

Figure 1, showing the camera setup and the melting ice cube with descending plumes, shown to the right.

The sinking behavior of the dyed plumes results from density differences when in contact with the still water. Namely, temperature and solute effects. The former is a product of meltwater from the ice cube being colder (~4 degrees Celsius) than the surrounding still water and since water density is inversely proportional to temperature in the regime from 0 to 4 degrees Celsius, due to water's hydrogen bonding and hexagonal crystal structure, the meltwater carries more density and therefore sinks towards the bottom (Sommerfeld, A. 1908). Additionally, the latter is conditioned by food dye concentration of dissolved solids that slightly increase the density, reinforcing the downward plume.

Additional analysis was conducted in order to see if the physics observed through this experiment agreed with literature. One can examine the Reynold's number in order to analyze the flow of the dyed plumes. In fluid dynamics, laminar vs turbulent flow regimes are predicted by the Reynolds number (Munson et al., 2009). Ultimately, this dimensionless quantity yields the ratio of the fluid's inertial to viscous forces. A higher Reynolds number indicates more turbulent flow due to inertial forces dominating viscous forces and vice versa for lower Reynolds numbers and is given by the equation below:

$$Re = \frac{\rho * u * L}{\mu} \qquad (1)$$

Equation 1. The Reynolds number, Re, is given by the fluid density (ρ), the fluid's velocity relative to the object (mason jar in this case) given by (u), the characteristic length of diameter (L) and the fluid's viscosity (μ).

Using video analysis, the fluid's velocity relative to the object was found to be ~0.01m/s. Further estimating the characteristic length of diameter ~0.01m and water's literature value for kinematic viscosity and density, the Reynolds number was found to be 100. This number indicated laminar flow especially in the early stages, consistent with the smooth tendrils observed. However, as the plume moves through the still water, broadening and entrainment cause it to become unstable and effectively yield a larger Reynolds number, coinciding with the more turbulent flow seen in later frames (Van Dyke, M. 1982).

3. Visualization techniques

Visualization was achieved by embedding four drops of food dye into the ice cube before freezing. As the ice melted, the contrasting blue dyed plumes were seen sharply. Direct light from a clip-on lamp provided side illumination in order to enhance the effect of the descending plumes. In post-processing, the background was digitally removed and replaced with neutral gray to eliminate some imperfections on the mason jar's surface and distractions.

4. Photographic Technique

The experiment was recorded on an iPhone 13 using the slow-motion mode at 240 fps with 1920x1080 resolution. The iPhone was positioned approximately 20 cm away from the side of the jar at mid height, perpendicular to the descending plumes.

Still frames were extracted from the original slow-motion video in an attempt to capture the different stages and transition from laminar to turbulent flow from the dyed plumes. Post processing techniques included cropping to isolate the plume, increases in brilliance (+20), contrast (+15) and saturation (+10) to enhance visibility. Digital removal of the background as well as an assembly into a four-panel collage for final presentation. It is also mention worthy to state that while extracting these still images reduced sharpness, it allowed the dynamic flow visualization to be captured more effectively.

5. Discussion and Reflection

The final composition reveals buoyancy-driven convection and laminar-to-turbulent transitions in a simple manner. The four-panel collage reveals temporal evolution as the plume transforms from a smooth initial stream to chaotic and turbulent mixing.

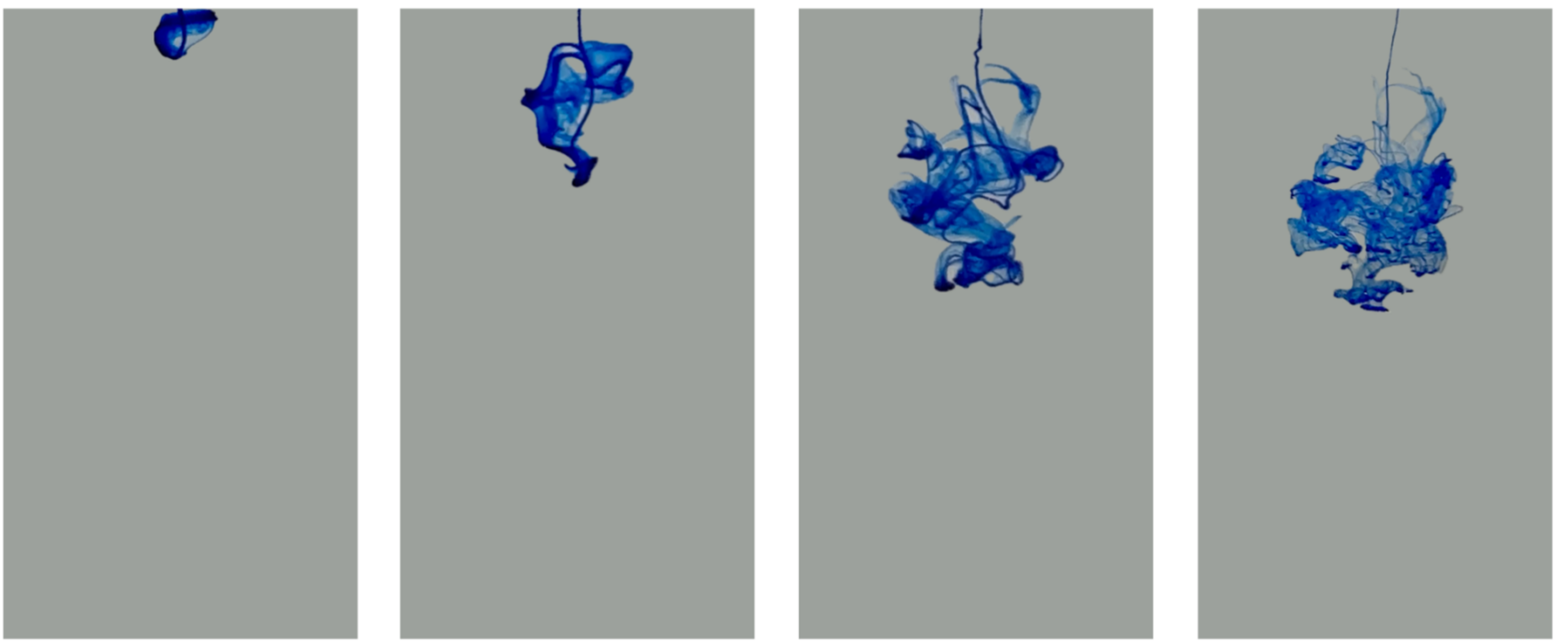

Figure 2. Final processed four-panel collage (note: Original submission on Canvas only featured the third image from the left)

In terms of strengths and limitations, I believe this experiment highlights interesting physics as well as the artistic component behind flow visualization in an accessible and clear demonstration of fluid dynamics. Limitations include reduced resolution and sharpness due to the extraction of the still frames. Improvements include back-illumination for more enhanced plume contrast as well as a DSLR camera for higher-resolution images.

Future work could examine the possibility of using distinct dye colors, simultaneously, in order to observe mixing or using warm dye water to see how it could react in a different way. Nonetheless, this experiment achieved its intent by balancing fluid dynamics and visual appeal.

References:

Munson, B. R., Young, D. F., Okiishi, T. H., & Huebsch, W. W. *Fundamentals of Fluid Mechanics*. John Wiley & Sons, 2009.

Sommerfeld, A. (1908). "Ein Beitrag zur hydrodynamischen Erklärung der turbulenten Flüssigkeitsbewegüngen (A Contribution to Hydrodynamic Explanation of Turbulent Fluid Motions)." *International Congress of Mathematicians*

Van Dyke, M. *An Album of Fluid Motion*. Parabolic Press, Stanford, CA, 1982.