# Density Layers and a sinking droplet in a glass cup

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MCEN 5151: Flow Visualization, Team Second Report



## Introduction

The goal of this experiment was to visualize how fluids of different densities separate into layers inside a clear glass cup. The cup has three layers: Canola oil on top, water mixed with cane sugar in the middle, and aloe vera gel at the bottom. I was particularly interested in the sharp boundary between the oil and the water and in a droplet that stretches into a thin neck as it sinks through the middle layer. My teammates, Alessandro and Matthew, helped with the experiment by lighting the cup from above and suggesting camera settings. With a blue flashlight shining down from above in a completely dark room, we captured the glowing, high-contrast image I was looking for.

## Flow and Physics

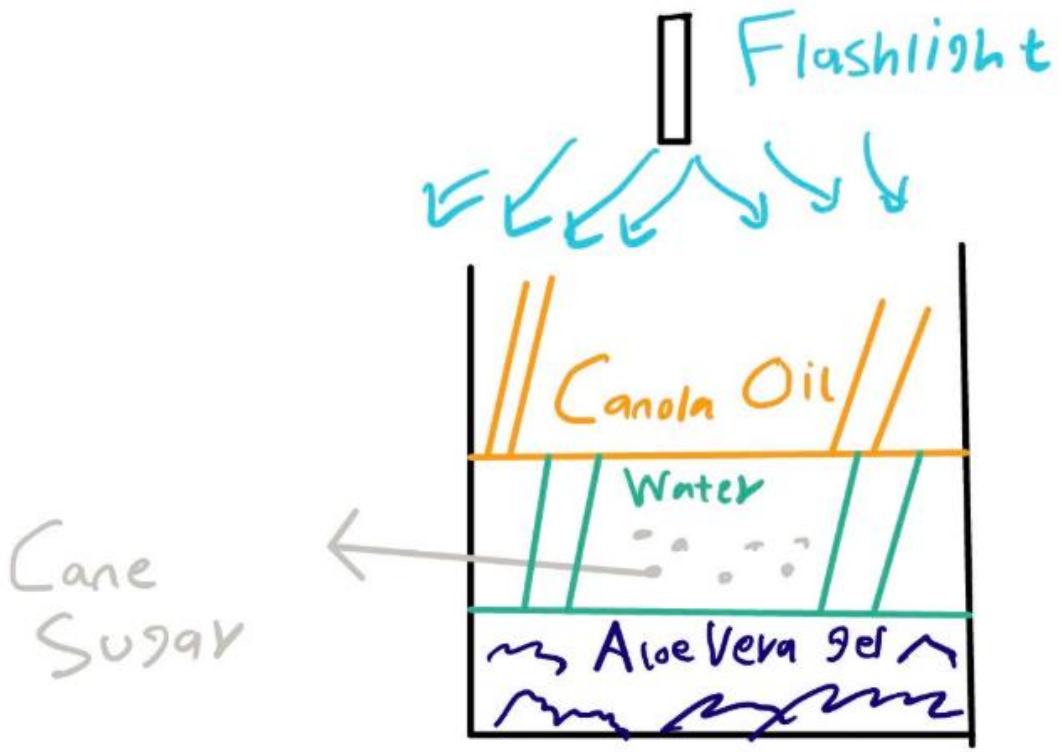



*Figure 1: Schematic of the experimental setup.*

In this experiment, the three fluids separate into layers because they have different densities. The denser fluid sinks, and the lighter fluid floats. Canola oil has a density of about 0.915 $g/cm^3$ (PubChem, n.d.), so it floats on top. On the other hand, the aloe vera gel sank to the bottom, which shows it is the densest of the three.

Oil and water are immiscible, so they don't mix. Interfacial tension keeps the boundary between them sharp, and in the image this boundary appears as the bright line of the bubble across the middle. For canola (rapeseed) oil and water, the interfacial tension is about 23.6 mN/m (Su et al., 2023). The layers are also stable because the densest fluid is at the bottom. Rayleigh-Taylor instability may appear only briefly, while a dense fluid is being poured onto a lighter one.

The interesting part of the image is the droplet hanging below the oil-water interface. Gravity pulls the droplet down, while interfacial tension tries to hold it in place. When the neck becomes thin enough, it pinches off; this type of breakup is driven by surface tension (Eggers, 1997). Therefore, to compare the effects of gravity and surface tension, we can use Bond number, which is given by:

$$Bo = \frac{\Delta\rho g L^2}{\sigma} = \frac{\left(125\,\frac{kg}{m^3}\right)\left(9.81\,\frac{m}{s^2}\right)(0.005\,m)^2}{0.0236\,N/M} = 1.30$$

Where:

$\Delta\rho = 1040 - 915 = 125\ kg/m^3$ is the density difference between the sugar water and the canola oil.

$g = 9.81\ m/s^2$

$L = 0.005\ m$

$\sigma = 0.0236$ N/m is the oil-water interfacial tension

A Bond number close to 1 means that gravity and surface tension are about equal. As a result, the droplet stretches into a teardrop shape instead of staying round or falling straight through.

Next, we find the Reynold number:

$$Re = \frac{UD}{v} = \frac{(5\ \times 10^{-3} m/s\ )(0.005\ m)}{(1.0\ \times 10^{-6} m^2/s)} = 25$$

Where:

$U$: 0.02 m/4s, is the estimated singing speed of the droplet

$D$: 0.005 m is the estimated droplet width.

$v = \ 1.0\ \times 10{-}^{6}\ m^2/s$ is the estimated kinematic viscosity of water.

A Reynolds number of 25 means the flow is smooth and laminar because viscous forces are strong enough to prevent turbulence.

Finally, to check whether the image is sharp, we calculate the distance d that the droplet moves during the exposure time of 1/40 s:

$$d = Ut = \left(5 \times \frac{10^{-3}m}{s}\right)\left(\frac{1}{40}s\right) = 1.25 \times 10^{-4}m = 125\mu m$$

The camera's field of view is approximately 18 cm across 6000 pixels, which means each pixel covers about $30\mu m$. Since the droplet moved about $125\mu m$ , motion blur is roughly 4 pixels. This may explain why the droplet's edges look slightly soft.

## Visualization Technique:

We added the aloe vera gel to the bottom of the cup. Then, we slowly poured water mixed with one spoonful of cane sugar on top. Finally, we gently poured canola oil on top so it would float without mixing. The setup was indoors in a completely dark room, with a dark background behind the cup. We lit the cup from above with a blue flashlight pointed down into the liquid. This lighting technique against the dark background created maximum contrast, making the glowing layers and droplets stand out clearly.

## Photographic techniques:

I captured the image using a Nikon D5200 with a 50 mm f/1.8 lens. I chose these settings because they gave the best possible resolution and suited the setup:

- Field of view: approximately 18 cm
- Distance from object to lens: approximately 40 cm
- Original resolution: 6000 x 4000 pixels
- Aperture: f/5.6
- Shutter speed: 1/40 s
- ISO: 4000

I processed the image in Darktable. I used the Exposure module to brighten the image, and then the Shadows and Highlights module to bring out the bubbles and the droplet in the lower part of the cup. I also cropped the image to remove the empty dark space around the cup.



*Figure 2: Final edited image*

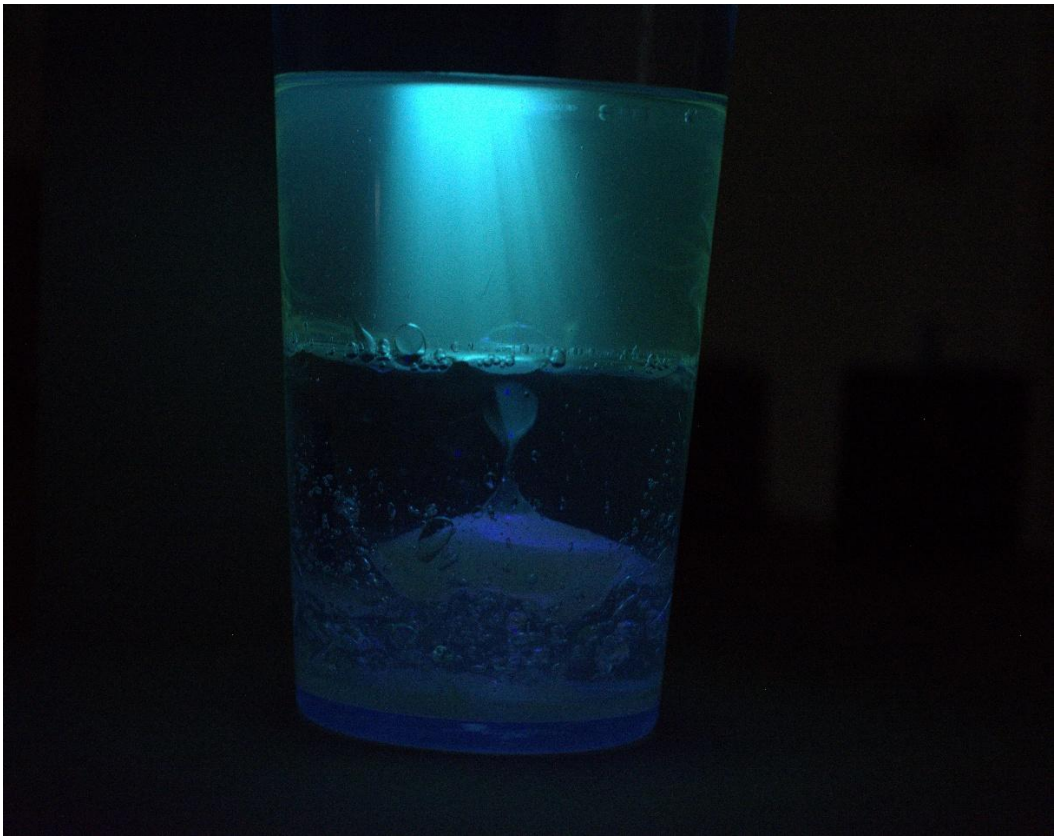


*Figure 3: Original unedited image*

## Reflection:

Overall, the photograph shows how fluids of different densities separate into stable layers and how a droplet stretches and pinches off under gravity and surface tension. The part I like most about this image is the glowing beam of light in the liquid mixture against the dark background. What I can improve is the spatial resolution, as Professor Koch mentioned in the critique session that round cups often have reduce spatial resolution and can create unclear detail. Next time, when photographing liquids with different densities, I will try a container with a different shape to see whether the spatial resolution improves.

## **Reference**:

Eggers, J. (1997). Nonlinear dynamics and breakup of free-surface flows. *Reviews of Modern Physics*, *69*(3), 865–930. https://doi.org/10.1103/RevModPhys.69.865

PubChem. (n.d.). *Canola Oil*. Retrieved October 31, 2026, from https://pubchem.ncbi.nlm.nih.gov/compound/Canola-Oil

Su, Y., Chu, Z., Gong, L., Wang, B., & Liu, Z. (2023). Assessment of Lubrication Property and Machining Performance of Nanofluid Composite Electrostatic Spraying (NCES) Using Different Types of Vegetable Oils as Base Fluids of External Fluid. *Chinese Journal of Mechanical Engineering*, *36*(1), 94. https://doi.org/10.1186/s10033-023-00929-y