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MCEN 5151-002

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*Figure 1: Dyed Oil in Water*

## Project Background

This image was created for the first assignment in the Flow Visualization course called Get Wet. The aim of this assignment is to gain experience with visualizing fluid flow phenomena and photography techniques. The image depicts red dyed oil in a glass of water. The oil was poured into the glass, and the shot was taken as the oil began to rise to the surface of the water. The goal of this image is to demonstrate buoyancy and the hydrophobic separation of oil and water on a macroscopic scale.

## Flow Set Up

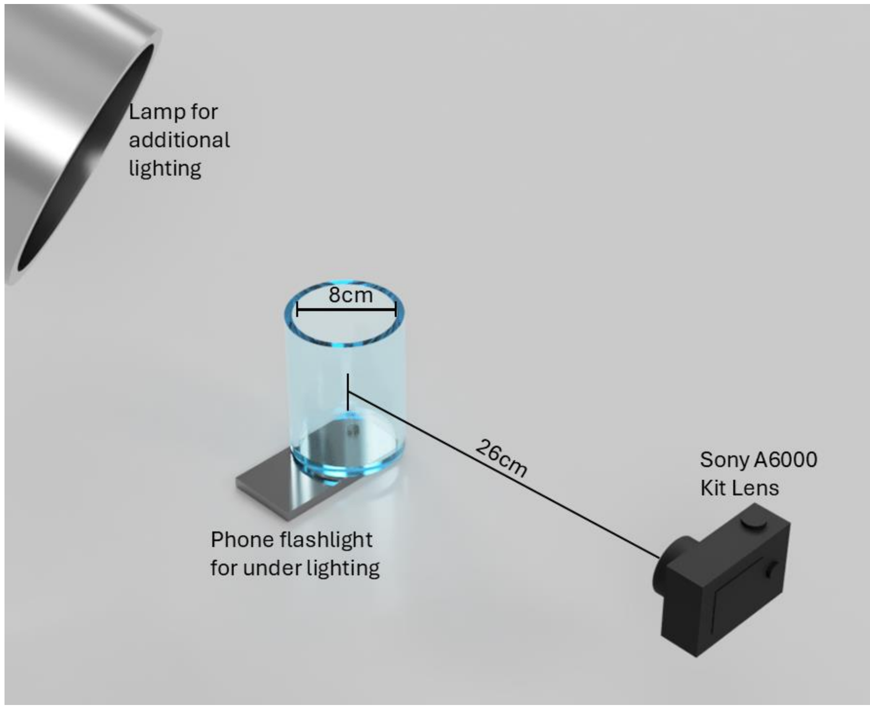


*Figure 2 Experimental Set Up*

The image was captured on a kitchen countertop with the set up shown in Figure 2. The flow phenomena required a high shutter speed which influenced the multiple lighting sources shown. The lighting sources were positioned to reduce glare on the surface of the glass. The image captures an area of approximately 7cm x 6.5cm within a glass of 4cm radius. The glass tapers slightly which can be seen at the edges of Figure 1. About 450mL of water was used with about 50ml of oil. The oil was colored with two drops of oil-based dye.

## Flow Physics

The primary phenomenon captured in this image is buoyancy. As the oil is poured into the water its surface tension is broken, forcing the oil into smaller bubbles. These bubbles sink to the bottom of the glass because of momentum. The buoyancy force then causes the oil bubbles to rise to the top of the glass. As they rise, some oil bubbles coalesce

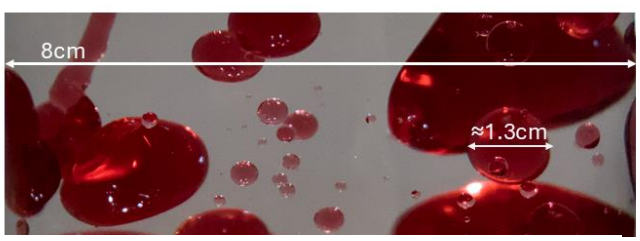


*Figure 3 Average Droplet Size*

into large oil droplets.

The droplets range in shape and size from nearly 4cm across to less than half a centimeter across. The average sized droplet is shown in Figure 3. The density of the oil is approximately 0.91 g/mL. Using the diameter of this droplet and assuming it remains spherical, the rise velocity (U) can be calculated. For the droplet to rise, its buoyancy must be greater than the drag force.

$$\Delta\rho g V = \frac{1}{2}\rho_w U^2 C_D A \qquad 1$$

Where $\Delta\rho$ is the difference between the oil and water density, $g$ is gravity, $V$ is the volume of the sphere, $\rho_w$ is the density of water, $C_D$ is the coefficient of drag, and $A$ is the cross-sectional area of the droplet. Assuming that the coefficient of drag is 0.3, the velocity is given by:

$$U = \sqrt{\frac{2\Delta\rho g V}{\rho_w C_D A}} = \sqrt{\frac{2 * (1000kg/\mathrm{m}^3 - 910kg/\mathrm{m}^3)(9.81m/s^2)\left(\frac{\pi}{6}0.013^3 m\right)}{(1000kg/\mathrm{m}^3)(0.3)\left(\frac{\pi}{4}0.013^2 m\right)}} = 0.2258m/s \qquad 2$$

The Reynold’s number is then:

$$Re = \frac{\rho_w\, U\, d}{\mu_w} = \frac{(1000kg/\mathrm{m}^3)(0.2258m/s)(0.013m)}{0.001\ Pa \cdot s} = 2.9 \times 10^3 \qquad 3$$

Another dimensionless quantity is the Eötvös or bond number. The bond number quantifies the force of gravity vs the surface tension. A lower number indicates that surface tension dominates over gravitational forces.

$$E_o = \frac{\Delta\rho g\, \mathrm{d}^2}{\gamma} \qquad 4$$

In this equation, $\gamma$ is the interfacial tension between the oil and water. The interfacial tension depends on the temperature and contamination in the fluid. For crude oil and water typical values range between 0.02 N/m – 0.03 N/m (Shoaib, 2025). Assuming the interfacial tension is 0.02 N/m, the bond number is:

$$E_o = \frac{\Delta\rho g\, \mathrm{d}^2}{\gamma} = \frac{(1000kg/\mathrm{m}^3 - 910kg/\mathrm{m}^3)(9.81m/s^2)(0.013m)^2}{0.02\ N/m} = 7.46 \qquad 5$$

The Reynold’s number and bond number inform the shape of the droplet.

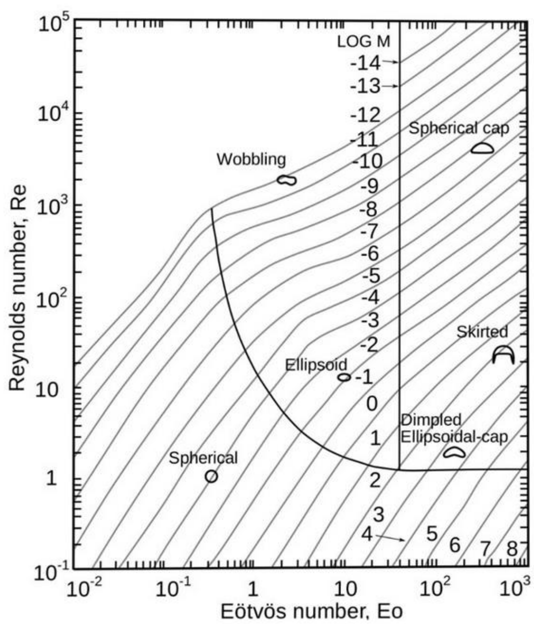


*Figure 4 Grace Diagram (Ziegenhein 2016)*

Using Figure 4, the Reynold's number of $2.9 \times 10^3$ and bond number of 7.46 show that the droplet is in the ellipsoid or wobbling regime. Since the droplet appears more spherical in Figure 1, it is likely that the Reynold’s number calculation assumes a coefficent of drag that does not match the observed interface conditions. In addition, the crude oil interfacial tension values likely overestimate the interfacial tension for vegtable oil in water. The large droplets discussed by Wairegi and Grace ranged from 5.1cm to 8.8cm in diameter and demonstrate the ellipsoidal-cap category (Wairegi & Grace, 1976). In Figure 1, largest drops are on a similar scale to those tested by Wairegi and Grace but do not appear to demonstrate the ellipsoidal-cap shape. In Figure 1, multiple drops interact with each other by coalescing and bouncing. Because of this interaction, it is difficult to determine whether the droplet shapes match the regimes reported by Wairegi and Grace.

## Visualization Techniques

To visualize this phenomenon, the oil was dyed with oil-based dye from Micheal's craft store. The oil used was a canola oil vegetable oil blend. Two drops of oil were added to approximately 50mL of oil. Between each trial the glass was washed and dried thoroughly to remove any contaminants. The oil was poured into the glass from approximately 8cm above the water's surface. A cellphone flashlight was placed underneath the glass to illuminate the flow without adding glare to the image. A lamp was placed off to the side behind the glass to add light and prevent glare.

## Photographic Techniques

The image was shot on a mirrorless Sony A6000 with a 16-50mm lens. The camera lens was approximately 26 cm away from the surface of the glass. The lens was focused just inside the surface of the glass. The original photo is 6000x3376 pixels and it was taken with 1/1250 shutter speed, f/5.6, 37.0 mm zoom, and 3200 ISO.

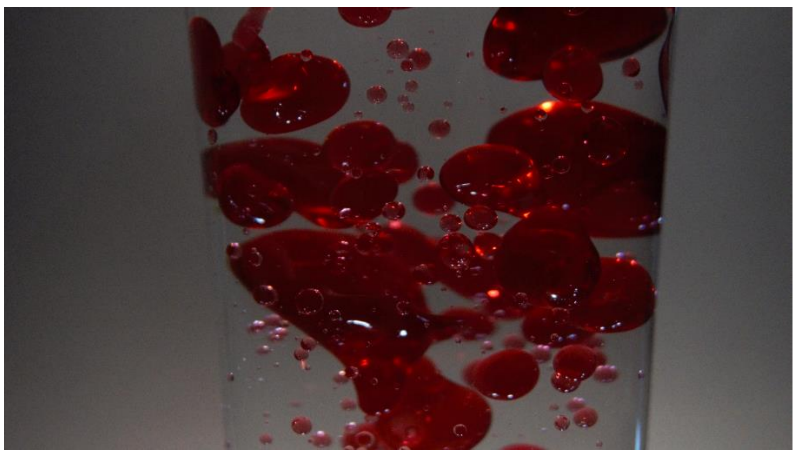

*Figure 5 Raw image*

The raw image shown in Figure 5 was cropped and edited. To edit the image, the exposure was increased and resulting noise removed. The contrast was slightly increased.

*Figure 6 Cropped and edited image*

The final image shown in Figure 6, better illustrates the flow phenomenon than the raw image.

## Conclusion

The image demonstrates buoyancy driven motion of droplets in immiscible liquids. The red dyed oil remained transparent, which added to the depth of the image and visual interest. I would like to better understand the shapes made by the interaction of oil and water before bubble formation and coalescence. For example, when first poured, the oil was a solid column which broke into smaller discrete droplets when hitting the wall or bottom of the glass. I was unable to capture the instant the column broke up. It would be interesting to explore how the individual droplets separate from the initial column before the coalesce into larger drops. In this experiment, I was hindered by my photography skills so I would like to improve for future assignments.

References

Shoaib, M. (2025, April 30). *What is interfacial tension, and how does it impact crude production?* Journal of Petroleum Technology. https://jpt.spe.org/what-is-interfacial-tension-and-how-does-it-impact-crude-production

Wairegi, T., & Grace, J. R. (1976). The behaviour of large drops in immiscible liquids. *International Journal of Multiphase Flow, 3*(1), 67–77. https://doi.org/10.1016/0301-9322(76)90036-7

Ziegenhein, Thomas. (2016). Fluid dynamics of bubbly flows. 10.14279/depositonce-5399.