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Flow Visualization: Get Wet
MCEN 5151
September 19th, 2025

For the first assignment of this course I decided to test my skills and experiment with fluids by using a video format. I experimented with several setups, but settled on recording a drop of nail polish falling into a vial containing acetone and olive oil, recorded in slow motion. This video was intended to show both a separation of fluids by density and the effect of nail polish falling in the liquids, which I found to be both fascinating and beautiful.

I created my setup by first staging a large white backdrop, then raising the square vial on a block, and setting a grey piece of fabric underneath. Next, I added olive oil and acetone to my container and allowed it to settle. I set up a flexible lamp over my container, allowing the light to shine almost directly onto the liquids. After setting up my phone, I had my roommate drop a singular drop of nail polish into the vessel, and recorded its fall.

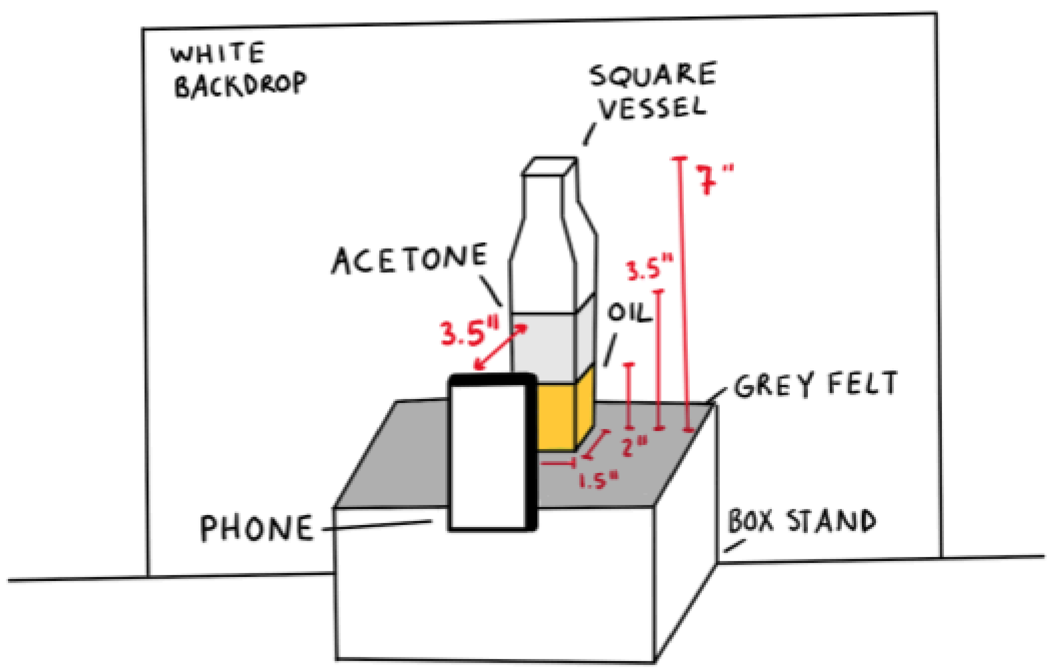

Fig. 1. Set-up Schematic

The nail polish being dropped into the vessel demonstrated a non-Newtonian liquid traveling through two liquid mediums of different densities. Because nail polish is a non-Newtonian fluid and its viscosity variable, it exhibits an intriguing deformation as it undergoes the stresses of entering the two fluids. Non-Newtonian fluids can have various classifications, but all either have a nonlinear relationship between the applied shear stress and rate or shear, or have a non-zero shear stress when the shear rate is zero [2]. Nail polish is considered to be a shear-thinning or pseudoplastic fluid, meaning that its viscosity decreases with an increased rate of shear force applied [8]. Although a common household fluid, the complexity of nail polish being a non-Newtonian liquid makes it difficult to characterize. The shear rheology of nail polish has been examined to some extent, but much is still unknown [5].

A plethora of things can be examined in this fluid flow. Because the nail polish is non-Newtonian, a Reynold's number cannot be easily calculated without knowing the apparent viscosity in each section of the different liquids. Instead, other things can be calculated, such as the velocities in each stage of fluid that the drop travels through, the buoyancy forces acting on the drop in each fluid, and the acceleration of the drop in each stage. Additionally, the Ohnesorge number can be calculated for both the acetone and olive oil. The Ohnesorge number is a non-dimensional number that relates a fluid's viscous forces to tension forces [1]. One would expect that the Ohnesorge number is significantly different in the acetone versus the olive oil, which could be a primary factor in the behavior of the drop in the two fluids. For the purpose of simplicity in the calculations, the fluids were given numbers based on the order that the droplet entered them. The fluid first passed through air (1), then acetone (2), then olive oil (3). Please also note that full calculations are given in the appendix, for better report flow.

The average velocities in each fluid stage can be approximated by using the video to find the time that the fluid entered and exited each stage and using the dimensions of the vial. Once found, these values can then be plugged into Equation 2. While traveling through air, the drop was found to have an average velocity of 0.31 m/s. The average velocity through acetone was found to be 1.6E-2 m/s. The average velocity through the olive oil was found to be 1.7E-3m/s. This aligns with what is seen in the video, where the droplet travels significantly faster through the air, slows down while traveling through the acetone, and then is significantly slowed traveling through the olive oil.

One of the other significant physical factors at play in this flow visualization is the distinct separation of fluids. This is due to the fluids having different densities, with the acetone being much less dense than the oil, allowing it to float on top. Because these fluids have different densities, the buoyancy forces acting on the drop differ by section. A simplified free-body diagram is shown below for the droplet in each fluid stage.

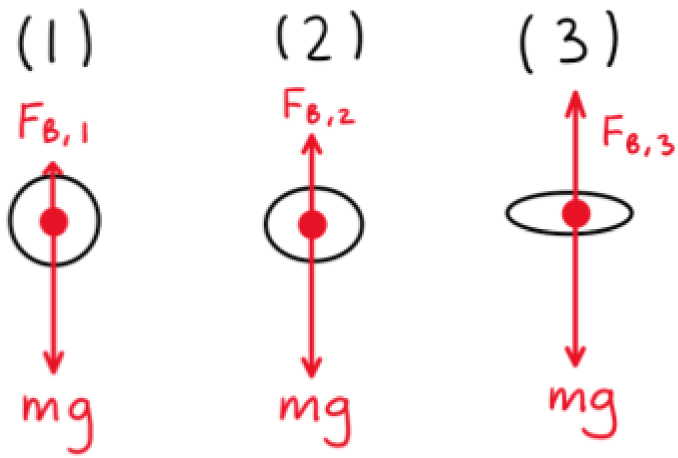

Fig.2. Simplified Free-Body Diagrams of the droplet as it passes through the 3 fluids

As can be seen from these free-body diagrams, the buoyancy force increases in each progressive fluid. The buoyancy force exerted on the drop in air was found to be $1.97 \times 10^{-7} N$, which is not significant when compared with the drop's weight force, 0.1962N. Because of this, we can consider the buoyancy force from air to be negligible in future calculations. In the acetone, the buoyancy force increased to be $1.31 \times 10^{-4} N$. Finally, in the olive oil the buoyancy force was found to be $1.47 \times 10^{-4} N$. This shows that as the drop falls, the upwards forces exerted on it increase, allowing it to somewhat decelerate as it falls. However, the buoyancy forces in the last two liquids are fairly close in value, and do not fully account for the drop's extreme deceleration.

By using Fig.2, one can also use a summation of forces to find the acceleration of the drop in each section. In the first section, where the drop falls through the air, the summation of forces is simply equal to $- m_{drop} g = m_{drop} a_{drop,1}$. When solved for the acceleration, the acceleration is found to be equal to g, as expected by Newton's Second Law. In the later fluid sections, the upwards force of buoyancy must be considered, so the summation of forces will result in $a_{drop,2} = \frac{F_B}{m_{drop}} - g$, where F_B is the buoyancy force of the fluid. The acceleration of the drop was found to be $a_{drop,2} =- 3.26 m/s^2$ in the acetone and $- 2.44 m/s^2$ in the olive oil.

Finally, we can calculate the Ohnesorge number. This number could prove to be insightful, as it could offer another explanation to why the drop slows more in each liquid, and the behaviors of it as it falls. In a previous study, this dimensionless number was used to predict the shape of a non-Newtonian droplet, as it can give insight into the effects that a fluid can have on an object within it [1]. The Ohnesorge number can be calculated using Equation 4:

$$Oh = \frac{\nu_{fluid}\sqrt{\rho_{fluid}}}{\sqrt{\sigma_{fluid}R_{drop}}}$$

Where ν_{fluid} is the kinematic viscosity of the fluid, ρ_{fluid} is the fluid's density, σ_{fluid} is the surface tension of the fluid, and R_{drop} is the approximate radius of the droplet. The Ohnesorge number for the drop in acetone was found to be 0.1296 and the Ohnesorge number in olive oil was found to be 0.1896. A higher Ohnesorge number indicates that viscosity plays a greater influence on the falling liquid. So, as expected, the droplet is more influenced by the olive oil than the acetone, because it is more viscous, allowing it to fall slower and undergo more warped behaviors.

In order to visualize this effect, I used a shiny darker-colored nail polish against lighter-colored fluids that it flows through, and a white backdrop. The container was a tall square-shaped vessel with a width and length of 1.5" and a height of 7", although the acetone-oil mixture only filled to approximately 3.5" up from the base, with the oil filling up 2" from the base. The acetone used for this experiment was "Up & Up 100% acetone nail polish remover", and was chosen for its known corrosive properties to polish. The olive oil used was "Pompeian Extra Virgin Smooth". The nail polish used was "LA COLORS Color Craze #409", which exhibited a shiny metallic silver color. When dropped, the nail polish was approximately ¼" in diameter as it entered the acetone layer. In order to provide sufficient lighting I used a flexible desk lamp, which I placed in manner to best illuminate the fluids over the vessel.

I recorded this fluid motion by taking a slow motion video on my i-phone 14. I decided upon this method after first experimenting and visualizing the flow without recording, and wanting to see it at a slower speed. While experimenting, I noticed that the polish appeared to "float" as it reached the bottom of the acetone layer and created interesting wakes as it entered the layer of olive oil. By recording at a slower speed, I realized that I could better see the physics of what was happening. The phone was placed approximately 3.5" away from the container, in order to have a stable position for filming. The video was recorded using my phone's main wide camera, which is equivalent to a 26mm lens with an equivalent wide aperture of f/1.5. The resolution of the saved video file is 650 x 1152 and the frame rate is 209.4 FPS. The only post-processing done was to increase the brightness of the video, as my lighting set-up was not as bright as I had intended.

This video reveals the fascinating physics of non-Newtonian liquids, especially as they travel through different mediums. It shows not only the dance-like motion of the drop, but also the wakes that it creates as it enters the final fluid and the distortion of the drop as it enters different mediums. I like that this video demonstrates an interesting physics concept in a beautiful way; however, if I were to redo it I certainly would change a few things. I dislike the lack of sufficient lighting in this video and would also like to try a thinner-walled vessel in the future. Additionally, I dislike that the image is cropped poorly, and that the vessel walls are not parallel with the video's frame. The fluid physics are shown somewhat well, although a thinner-walled container would likely help in better demonstrating the drop's changes through the different mediums. This experiment did leave me with several questions. Most of all, I'm curious as to why the drop seems to change shape before it enters the oil, why it looks almost tornado-like. I'm also curious to know more about the fluid mechanics of non-Newtonian fluids and how they behave in other conditions. Finally, I'm intrigued to know if other non-Newtonian fluids would have a similar effect with the same fluid set-up, which is where I would ideally like to further develop this idea.

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APPENDIX:

A. Calulations

a. General Properties, Assumptions, and Notes:

Property (With reference #)	Name	Value
$\rho_{air,\,20\circ C}$ (4)	Density of air	0.001204 g/mL
$\rho_{acetone,\,20\circ C}$ (10)	Density of acetone	0.8 g/mL, 800 kg/m^3
$\rho_{oil,\,20\circ C}$ (6)	Density of oil	0.9 g/mL, 900 kg/m^3
$\rho_{drop,\,20\circ C}$ (7)	Density of droplet	1.2 g/mL
$\nu_{acetone,\,20\circ C}$ (3)	Kinematic viscosity of acetone	$4.10\times 10^{-5} m^2/s$
$\nu_{oil,\,20\circ C}$ (3)	Kinematic viscosity of olive oil	$6.37\times 10^{-5} m^2/s$
$\sigma_{acetone,\,20\circ C}$ (9)	Surface tension of acetone	0.0252 N/m
$\sigma_{oil,\,20\circ C}$ (11)	Surface tension of olive oil	0.032 N/m
D_{drop}	Diameter of droplet	$\frac{1}{4} in$, 0.00635m
R_{drop}	Radius of droplet	$\frac{1}{8} in$, 0.003175m
m_{drop}	Mass of Droplet	0.02g
$V_{drop} = V_{disp}$	Volume of Droplet, Volume displaced	0.0167mL, 1.67E-8m^3
$W_{drop} = m_{drop} g$	Weight force of droplet	0.1962N

Assumptions:

- The experiment was conducted at room temperature, which can be approximated as $20°C$

- The experiment was conducted at 1atm and the atmospheric pressure does not have a significant effect on the droplet's fall through the vial
- The acceleration of gravity is $9.81\ m/s^2$
- The mass of one drop of nail polish is 0.02g

Notes:

- The density approximation of nail polish was found using ChatGPT, and was verified by myself after checking a paper that was provided as a reference (Referance__)
- The drop's volume was calculated using Equation 1 below, and the assumed mass of one drop of nail polish

Equation 1: $V_{drop} = \frac{m_{drop}}{\rho_{drop}}$

$$V_{drop} = \frac{0.02g}{1.2\ g/mL} = 0.0167mL$$

b. Velocity Calculations:

Equation 2: $V = \Delta x/\Delta t$

Fluid Section	Entry Time (s)	Exit Time (s)	Δt (s)	Distance Traveled (in)	Velocity (in/s)	Velocity (m/s)
Air (1)	5.5	5.81	0.31	3.5	12.07	0.31
Acetone (2)	5.81	8.14	2.33	1.5	0.64	1.6E-2
Olive Oil (3)	8.14	39.0	30.86	2	0.065	1.7E-3

c. Buoyancy Calculations:

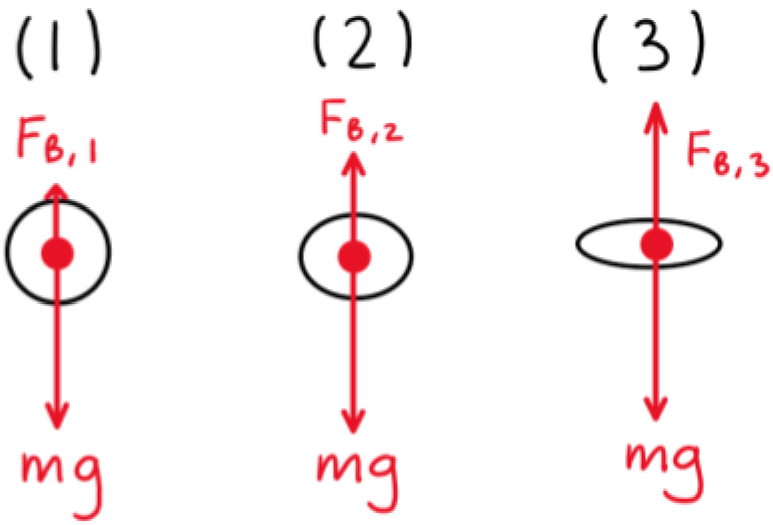

Fig.2. Simplified Free-Body Diagrams of the droplet as it passes through the 3 fluids

Equation 3: $F_B = \rho_{fluid}\, g\, V_{disp}$

Buoyancy in Air:

$F_{B,1} = \rho_{air}\, g\, V_{disp}$

$F_{B,1} = (0.001204\ g/mL)(\frac{1\ kg}{1000\ g})\ (9.81\ m/s^2)\ (0.0167 mL)$

$F_{B,1} = 1.97 \times 10^{-7} N$

Buoyancy in Acetone:

$F_{B,2} = \rho_{acetone}\, g\, V_{disp}$

$F_{B,2} = (0.8\ g/mL)(\frac{1\ kg}{1000\ g})\ (9.81\ m/s^2)\ (0.0167 mL)$

$F_{B,2} = 1.31 \times 10^{-4} N$

Buoyancy in Olive Oil:

$F_{B,3} = \rho_{oil}\, g\, V_{disp}$

$F_{B,3} = (0.9\ g/mL)(\frac{1\ kg}{1000\ g})\ (9.81\ m/s^2)\ (0.0167 mL)$

$F_{B,3} = 1.47 \times 10^{-4} N$

d. Acceleration Calculations:

$\Sigma F = ma$

Acceleration in Air:

$- m_{drop} g = m_{drop} a_{drop,1}$

$a_{drop,1} = - g$

$a_{drop,1} = - 9.81 m/s^2$

Acceleration in Acetone:

$F_{B,2} - m_{drop} g = m_{drop} a_{drop,2}$

$a_{drop,2} = \frac{F_{B,2}}{m_{drop}} - g$

$a_{drop,2} = \frac{1.31 \times 10^{-4} N}{0.02 g (1 kg/1000 g)} - 9.81$

$a_{drop,2} = - 3.26 m/s^2$

Acceleration in Olive Oil:

$F_{B,3} - m_{drop} g = m_{drop} a_{drop,3}$

$a_{drop,3} = \frac{F_{B,3}}{m_{drop}} - g$

$a_{drop,3} = \frac{1.47 \times 10^{-4} N}{0.02 g (1 kg/1000 g)} - 9.81$

$a_{drop,3} = - 2.44 m/s^2$

e. Ohnesorge Number Calculations:

Equation 4: $Oh = \frac{\nu_{fluid} \sqrt{\rho_{fluid}}}{\sqrt{\sigma_{fluid} R_{drop}}}$

Ohnesorge Number for Acetone:

$$Oh_{acetone} = \frac{\nu_{acetone}\sqrt{\rho_{acetone}}}{\sqrt{\sigma_{acetone}R_{drop}}}$$

$$Oh_{acetone} = \frac{(4.10\times10^{-5} m^2/s)\sqrt{(800\ kg/m^3)}}{\sqrt{(0.0252\ N/m)(0.003175m)}}$$

$$Oh_{acetone} = 0.1296$$

Ohnesorge Number for Olive Oil:

$$Oh_{oil} = \frac{\nu_{oil}\sqrt{\rho_{oil}}}{\sqrt{\sigma_{oil}R_{drop}}}$$

$$Oh_{oil} = \frac{(6.37\times10^{-5} m^2/s)\sqrt{(900\ kg/m^3)}}{\sqrt{(0.032\ N/m)(0.003175m)}}$$

$$Oh_{oil} = 0.1896$$