

Get Wet Report

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Objective

The purpose of this report is to describe the process, purpose, and physics of the Get Wet assignment. This assignment is an introductory assignment to creatively explore flow visualization. The visual created is an exploration of surface tension, interfacial energy, and the Weber number.

Procedure

The flow apparatus used is made from common equipment one can find in a classroom. This includes a glass cup, peeled crayons, and a kettle or other way to heat up water. First, the water is heated to 195 degrees Fahrenheit and poured into the glass. Ensure that the glass is room temperature as to avoid breaking the glass. Then, a peeled crayon is then inserted into the hot water about halfway stirred in a circle to allow for the melting wax to transfer from the surface of the crayon to the surrounding water. A diagram of this setup can be seen in Figure 1.

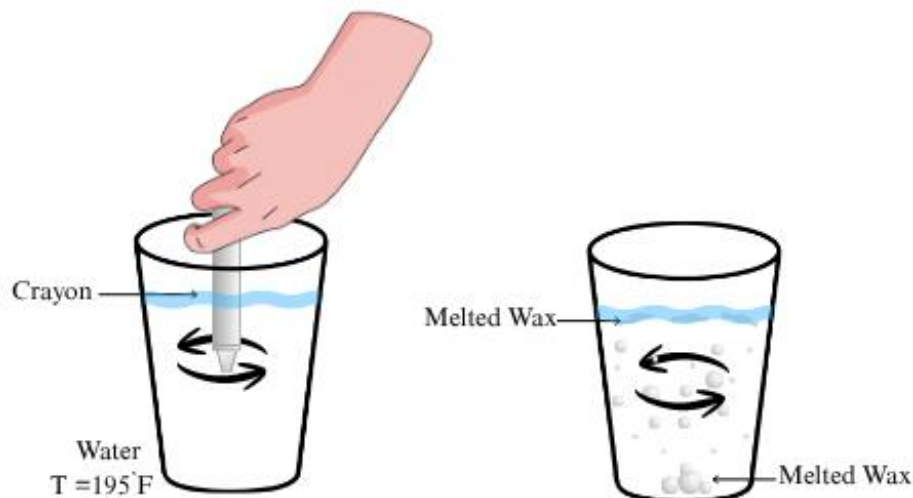


Figure 1: Diagram of set up and procedure. Notice there are different wax behaviors in the water. A top film, suspended spheres, and spheres at rest at the bottom of the container.

As the wax melts away from the crayon forms spheres that dance around in the water. This movement is the visual captured in this assignment.

Technical Analysis

As the wax melts, its hydrophobic properties make it want to stick to the crayon or spread out on top of the water's surface. The wax wants to spread out because of surface tension. Surface tension comes from intermolecular attraction. Molecules within a liquid experience attraction from molecules around them. At a liquid's boundary, those forces are unbalanced, creating surface tension [4]. For this system specifically there are three interfaces: wax and water, wax and air, and water and air. Each interface has its own surface tension. The balance among them helps determine whether the wax will form droplets, blobs, or thin layers at the top. In the case of the wax observed sitting at the water surface, the wax has three interfaces, air, wax and water. Which all have different surface tensions, γ .

$$\gamma_{WA} = \text{water} - \text{air surface tension}$$

$$\gamma_{WaxA} = \text{wax} - \text{air surface tension}$$

$$\gamma_{WaxW} = \text{wax} - \text{water}$$

$$\gamma_{WA} > \gamma_{WaxW} > \gamma_{WaxA}$$

Since the surface tension of water and air is larger than the surface tension of water and wax and air and wax, the system pulls the wax to cover more of the surface area to balance the forces and reduce the interfacial energy [3][4]. This is why it is observed that the wax spreads across the surface of the water in a sheet instead of clumps, as seen in Figure 2.



Figure 2: Photo of wax sitting on top of the water due to surface tension.

This behavior, although interesting scientifically, does not create as interesting of a visual. To get around this the crayon is spun in a circle, allowing for the centrifugal forces to push the wax from the crayon stick and into the water. The wax, now suspended in water, is experiencing interfacial tensions between only wax and the surrounding water. Interfacial energy, E , can be approximated as

$$E \approx \gamma A \quad (1)$$

where A is the surface area of the wax-water interface. The systems naturally tend toward a lower energy state and since the amount of wax is fixed, it can lower its interfacial energy by minimizing its surface area [2]. For a given volume, a sphere has the smallest possible surface area. Thus, the wax forms into spheres as seen in Figure 3.



Figure 3: Image of molten wax forming spheres when surrounded by water.

The reason that the wax stays in a spherical shape without being deformed by the flow is due to the Weber number, We .

$$We = \frac{\rho_w v^2 D}{\gamma} \quad (2)$$

The Weber number is a dimensionless number that measures the ratio of inertial forces to surface tension forces at a fluid's interface [2]. For the experiment calculating the Weber number provides information of whether the wax will stay spherical or deform due to the present flow. Experimentally it was seen that the wax does in fact retain its spherical shape. Now, we can prove it theoretically. Since there are many wax spheres of different sizes and traveling at different velocities, only one will be analyzed. The sphere is measured at about 3mm, velocity was analyzed using the video and tracking distance over time, and the density of water and

surface tension between the wax and the water can be looked up in tables [1][3]. These measurements can be found in Figure 4.

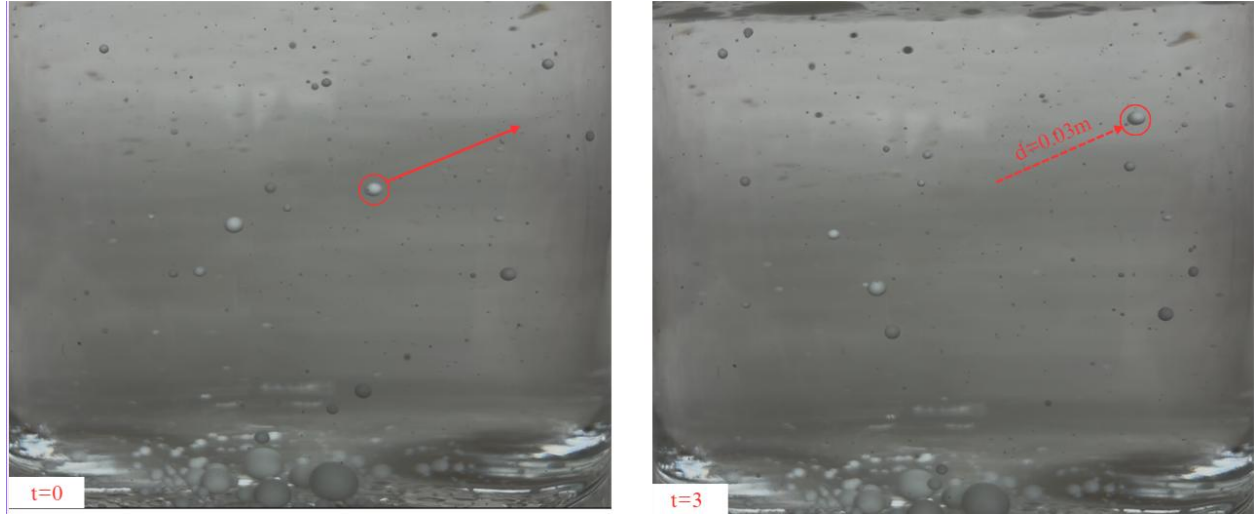


Figure 4: Still shots of video showing the approximate measurements of the velocity of the chosen wax sphere.

Thus, the values are

$$\rho_w \approx 964 \frac{kg}{m^3}$$

$$v \approx 0.01 \frac{m}{s}$$

$$D \approx 0.003 m$$

$$\gamma \approx 0.03 \frac{N}{m}$$

$$We = \frac{964 \frac{kg}{m^3} (0.01 \frac{m}{s})^2 0.003m}{0.03 \frac{N}{m}} = 0.00964 \ll 1$$

The Weber number being much less than one means that the inertial forces from the flow are not enough to deform the wax, thus the wax stays spherical. This is consistent with the experiment as it is seen that the sphere does not deform while moving.

Techniques

Visualization Techniques

As described in the procedure section, the visualization techniques used were quite simple. A simple marked boundary was created using opaque crayon wax and transparent water. The color

of the crayon wax was experimented upon and determined that the white wax created the more interesting image as seen in Figure 5.



Figure 5: White crayon wax vs colored crayon wax

White was chosen because it did not take away from the physics of the fluid interaction and highlighted the shadows of the sphere. The sphere's looked almost two dimensional because of the crisp shadows the white wax was able to bring out. Natural light was used as a constant and continuous light source to further highlight those shadows. To avoid glare from the glass, a white sheet was used to diffuse the sunlight and block distractions in the background.

Photographic techniques

The visual was captured using an iPhone 17e camera. This decision was made based on the accessibility and comfortability of the iPhone, as it is a device I have used many times to photograph and constantly carry with me. The iPhone 17e uses 48MP Fusion camera systems and the visual was captured at 26mm, f1.64 at 30 FPS. The height and width of the image is 1930 x 1080 pixels. The camera was about 3 inches away from the glass with no zoom.

The visual was later post processed, where the exposure and contrast was increased. A before and after can be seen below in Figure 6,

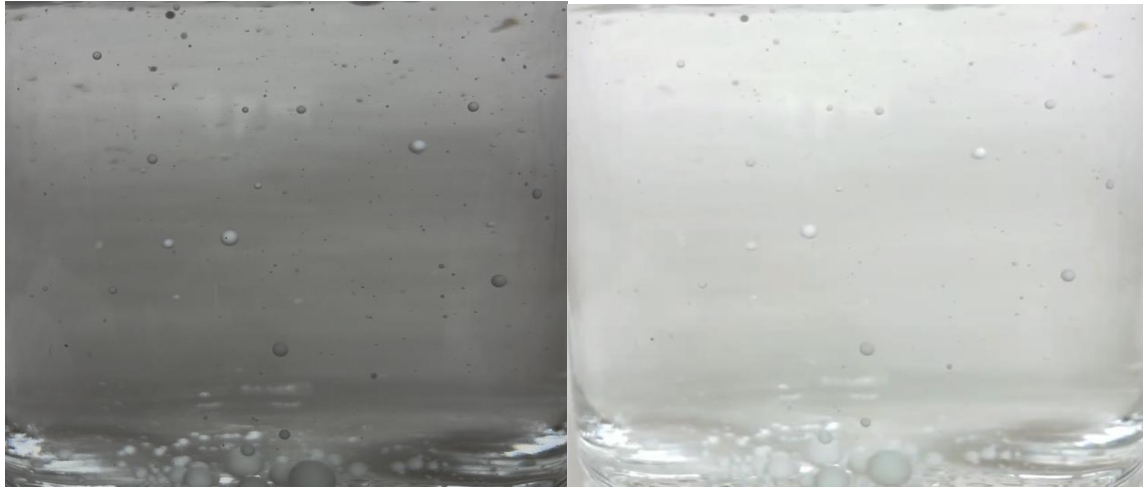


Figure 6: Before (left) and after (right) image processing.

Conclusion

The visual captured for this assignment is an interesting representation of surface tension. There are multiple cases of surface tension displayed here including the wax spread across the surface of the water and the spheres of wax following the flow of water. It was shown why the wax spread across the surface of the water, why the wax forms spheres when surrounded by water, and it was proven that the inertial forces from the flow are not strong enough to deform the sphere. This visual does an excellent job of balancing physics and the beauty of flow visualization.

There are many more physics phenomena present in this visual that were not explored in this report. Including, buoyant forces, turbulent vs laminar flow, heat transfer affects, and solidification rates. Next steps would be exploring these variables and determining what affect they have on system. There were also some simplifications made in this report such as constant velocity, approximate measurements, and approximate surface tension values. In the future, using equipment that would provide better measurements of the system would further improve the experiment.

References

¹ Adamson, Arthur W.; Gast, Alice P. (1997-08-18). [*Physical Chemistry of Surfaces*](#) (PDF) (6th ed.). New York: Wiley-Interscience. pp. 36–38. [ISBN 978-0-471-14873-9](#).

² Bush, John W.M. ["Surface Tension Module"](#) (PDF). Department of Mathematics, [MIT](#).

³ Butt, Hans-Jürgen; Graf, Karlheinz; Kappl, Michael (2006). *Physics and Chemistry of Interfaces*. Wiley. p. 9. [ISBN 978-3-527-60640-5](#).

⁴ Sears, Francis Weston; Zemanski, Mark W. (1955) *University Physics 2nd ed.* Addison Wesley