Oil Bubbles in Water

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1 Introduction

This study set out to explore how oil interacts with water when oil droplets are introduced into a water bath, all observed through the lens of a high-speed camera. We were driven not only by scientific curiosity but also by the sheer beauty of the process. As the oil met the water, the oil droplets took on a golden hue, creating a striking contrast against the pink background of the water. This lovely pink backdrop was the result of using incandescent light on a white poster board. In essence, this study was an artistic and scientific journey, capturing the graceful interplay of oil and water, where each droplet of oil became a tiny golden gem against the backdrop of a rosy underwater world, all illuminated by the soft glow of incandescent light.

This study used a high-speed camera that can capture thousands of frames in just a second. This allowed us to take a very close look at how oil and water behave when they interact. You can see the results of our work in a video by following this link: https://www.youtube.com/watch?v=rERgL9Tg3J0. The high-speed camera gives us a detailed view of what happens during the process. You can watch the oil and water mixing, the colors changing, and the tiny details of each droplet's journey in slow motion. It's a fascinating blend of science and art captured for you to enjoy in the video.

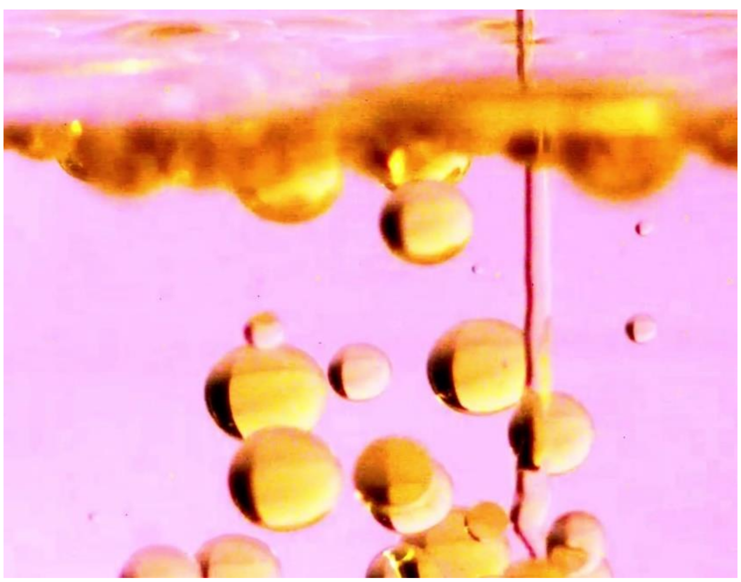

Figure 1: Oil in Water featured image

2 Flow Phenomenon

The interaction of oil and water in this setup is driven by buoyancy, hydrophobic, and lipophilic forces. As oil is dropped into a water bath, the hydrophobic properties of oil cause it to reduce its surface area with water. This reduction occurs by forming spherical bubbles because spheres have the smallest surface area. Since oil is lighter than water, buoyant forces act on the oil bubbles, causing them to rise and float on the water's surface. At the water's surface, the oil molecules are attracted to each other due to lipophilic forces, leading them to increase the surface area in contact. Consequently, the bubbles combine to create a layer of oil at the water's top.

Chen et al.[1] discuss the effect of oil-water interfacial tension on the process of oil droplets in water. As the oil-water interfacial tension increases, the droplets spread at faster speeds and cover longer distances. This is due to the higher rate of conversion between free surface energy and kinetic energy, which accelerates with increased surface tension.

A study by Bera et. al[2] provides a detailed examination of oil droplet coalescence in water. They assert the presence of a coalescence event frequency, denoted as "*f*," which can be calculated as follows: The volume ratio, $\varphi = V_f / V_i$, where Vf represents the final volume of the oil droplet after coalescence, and V_i is the initial oil droplet volume before coalescence. The mean number of coalescence events can be calculated as $N_{coal} = \varphi - 1$. Assuming that a droplet exists for a specific residence time (t_{res}), the frequency of coalescence is then estimated as $f = N_{coal} / t_{res}$.

Moore and Richmond[3] discuss a weak -OH interaction (hydrogen bonding) between alkane molecules in oil and water molecules near the oil layer at the water surface. This suggests that some water molecules orient themselves toward the hydrophobic oil molecules at the interface, contrary to the typical hydrophobic nature of oil and water interactions.

Another intriguing effect observable in the video is the transformation of the oil stream entering the water, shifting from turbulent to streamlined flow. When the oil stream initially contacts the water, it displays turbulence due to its high Reynolds' Number. However, as the oil stream advances into the water, various forces, including buoyancy and hydrophobic drag forces, work together to slow it down, resulting in a more orderly, streamlined flow.

3 Methods

The materials used in the experiment are as follows:

- A 5 x 5 x 10 (cm) transparent plastic cuboid vessel
- Phantom Miro C110 high speed camera
- PCC software
- Charger for the camera: 24V 3-amp output adaptor with 3 pin female connector
- Micro-NIKKOR 105 mm 1:28 lens
- Two incandescent light bulbes
- Tripod to hold the camera
- White Posterboard
- Vegetable Oil used in cooking
- Tap Water

3.1 Procedure

1. Preparing the Experiment: We started by pouring water into a container.
2. Camera Setup: Next, we set up the high-speed camera. We followed the instructions in its manual to make sure it was connected properly.
3. Camera Software: We used special software called "PCC" on a laptop to see what the camera was recording.
4. Focusing the Camera: To make sure the camera was looking at the right spot, we placed a ruler in the water. This helped us adjust the camera's focus and position.
5. Recording the Action: Once the camera was all set up, we slowly poured oil into the water. While doing this, the camera recorded everything that happened.
6. Adjusting Settings: We kept an eye on the video quality and made adjustments as needed. This included changing things like the resolution and lighting to get the best possible view and details of how the oil and water were moving together.

So, it was a step-by-step process to make sure we captured the interaction between the oil and water in the best way possible using the high-speed camera.

3.2 Camera and Lighting

The camera used was a Phantom Miro C110 camera with a Micro-NIKKOR 105 mm 1:28 lens, which is a prime lens (with no zoom). The resolution used was 768 x 768, resulting in a frame rate of 1215 fps. The distance between the camera and the object was 0.46 meters, and the video was recorded for approximately 30 seconds.

3.3 Post-Processing

The original image underwent post-processing using Microsoft Clipchamp settings to adjust brightness and contrast. The frame was cropped to fill the frame with the oil droplets inside the water. The music "Rising Star" from Microsoft Clipchamp was added. To obtain a still frame from the video, the video was paused at the desired time step, and a snapshot was taken.

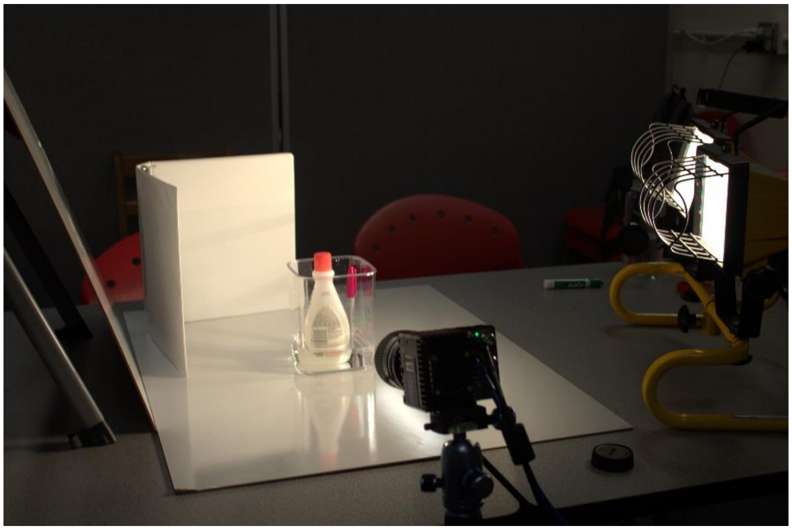

Figure 2: The setup used for imaging

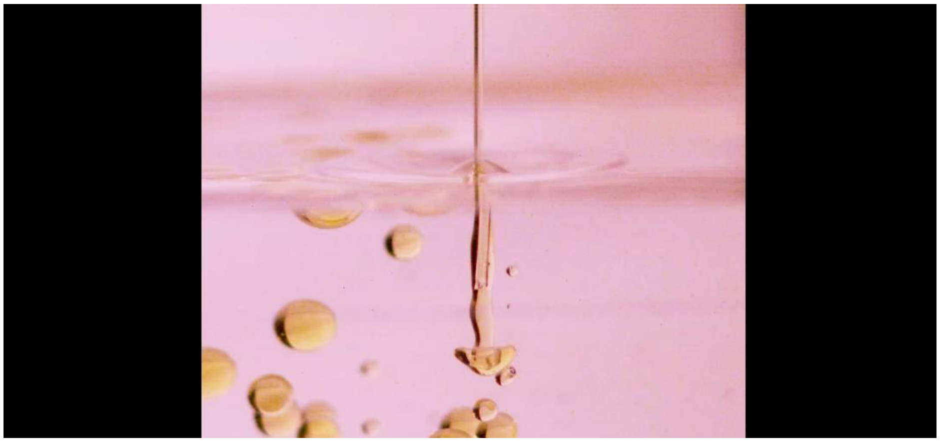

Figure 3: a) Snapshot from the unedited video

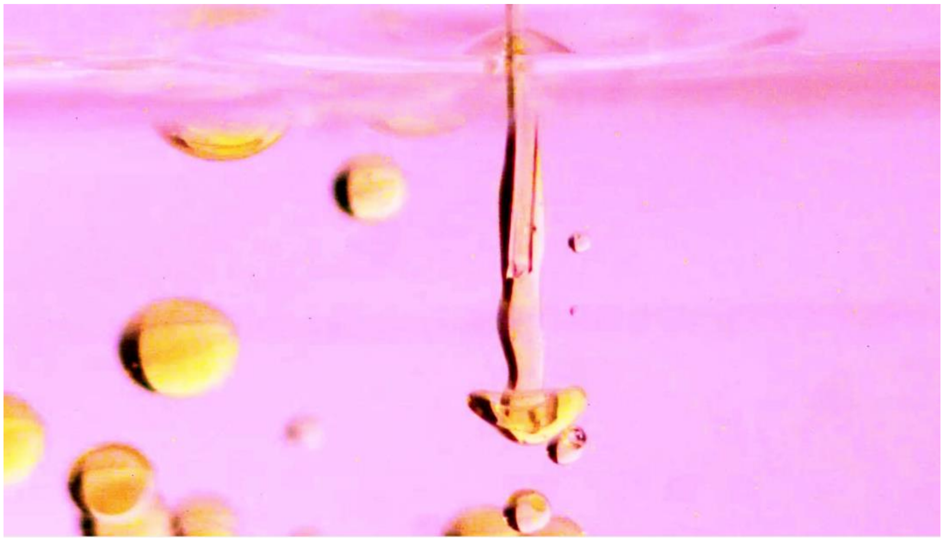

Figure 3: b) Snapshot from the edited video

4 Observations

The video captured intriguing details, such as the transformation of an oil stream into oil droplet bubbles. These bubbles ascended to create a layer of oil on the surface. Additionally, the collision of the oil stream with the rising oil bubbles altered their shape and trajectory, resulting in captivating observations. This project allowed me to acquire skills in high-speed videography, which is a crucial tool in scientific videography.

Throughout this endeavor, my primary challenge lay in transferring the large video files from the camera software to the video editing software. Converting the raw file into an mp4 format was necessary, but it did lead to a slight reduction in video quality. In the future, I aim to explore methods to mitigate this quality loss during file format conversion and editing.

Acknowledgements

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References

[1] Chen, Z., Yang, X., Wang, B., Dai, J., & Bai, Z. (2021). Numerical simulation of oil droplets spreading on solid surface in water. *Journal of Physics*, 1948(1), 012215. https://doi.org/10.1088/1742-6596/1948/1/012215

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