Marangoni Effect

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Flow Visualization, MCEN 5051

Image / Video Assignment #

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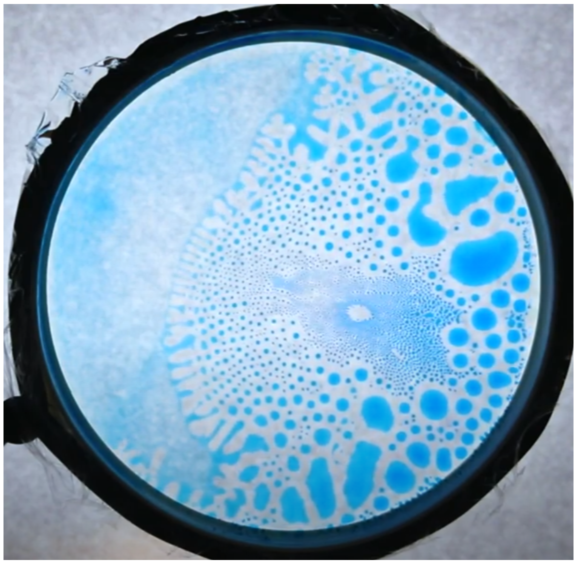

Introduction

The goal of the second video project was still similar to that of the first. I wanted to image fluid dynamics in an aesthetic and creative way. However, with the experience of the first project under my belt, I wanted to take on a more complicated fluid setup. For this project, I took a video of the Marangoni effect. I used a dyed alcohol and water solution in oil to create the effect. The alcohol evaporates from the water and creates thousands of water droplets. That transformation process was extremely visually satisfying. While filming, I also captured some unexpected fluid dynamics.

Fluid Dynamics Used

The Marangoni Effect

The Marangoni effect is a direct result of a surface tension gradient within a fluid. A fluid with higher surface tension will have a stronger pull on the surrounding liquid than that of a lower surface tension fluid. As the surface tension changes the equilibrium between the fluid's edges changes and the strength at which these fluids pull on one another changes. There are many ways to change a fluid's surface tension such as temperature and viscosity. In this experiment, the viscosity was changing as the alcohol evaporated from the water. As the surface tension begins to change a large patch of the water-alcohol mixture gets spread across the surface of the oil. The speed of this expansion can be modeled with this equation:

$$u \approx \frac{(\gamma_{\rm w} - \gamma_{\rm s})^{2/3}}{(\mu\rho)^{1/3} r^{1/3}} \approx \frac{10^{-2}}{r^{1/3}} \;\; ; \;\; (r \text{ in m})$$

Derived from that expression is the dimensionless value known as the Marangoni number. The Marangoni number can be used to describe the relative effects of surface tension and viscous forces. The Marangoni number is defined below:

$$u^{3/2} \approx \frac{(\nu r)^{1/2}}{\mu} \left(\frac{\partial \gamma}{\partial r}\right) \approx \frac{r^{1/2}}{(\mu\rho)^{1/2}} \frac{\gamma_{\rm w} - \gamma_{\rm s}}{r}$$

After the fluid has expanded to its max radius (which depends on the viscosity of the water-alcohol mixture) the alcohol evaporation begins to increase the viscosity of the mixture and causes the radius to shrink. As it shrinks it leaves behind hundreds to millions of droplets.

Producing the Flow

The flow was not hard to set up, however, getting the flow to look ideal was not trivial. The first step is to pour a small layer of sunflower oil into a container. Next, the alcohol and water mixture must be created. I found that a near 50/50 water to alcohol ratio worked well when using 99% isopropyl alcohol. I used ballpoint pen ink to dye the water-alcohol mixture. Then I used a syringe to set a drop of the water-alcohol mixture directly on top of the oil layer. I observed that changing the ratio of the water-alcohol mixture greatly impacted the result of the flow.

Camera Setup and Image Acquisition

The setup for this experiment was very complicated. I used a custom 3-D printed ring with a clear wrap to hold the oil. That was placed on a lightbox and my tripod was set above that with the camera facing down. I used a variety of lenses to capture different zooms and detailed shots of the flow. Mainly I used a 50mm f/1.8 prime lens. At times I reverse mounted the lenses to get macro shots. I filmed on a Canon 1dx mark ii DSLR camera at 120fps in 1920p x 1080p resolution.

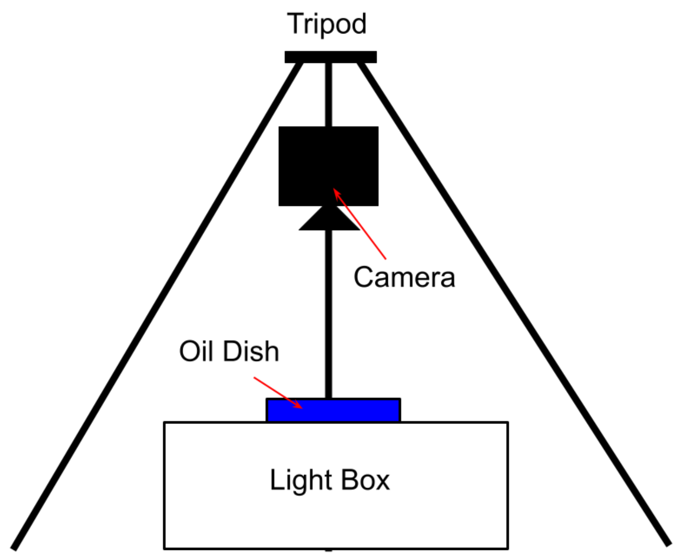

Fig.4 Camera Setup Diagram

The video was post-processed and edited in Adobe Premiere Rush. The main edits were to the time scale and color grading. The footage was sped up to try and meet the 2-minute requirement and to show the entirety of the flow timeline. Most of the color grading done was to highlight the subject. This was done to better show the fluid, as it was transparent and backlit.

Conclusion

The goal of project 2 was met with this experiment. I was able to test my skills from the first project on a more complicated experiment and I also learned a lot more. I gained more experience with my understanding of lighting fluid elements and using lightbox techniques to diffuse harsh lighting. I am very pleased with the result and I personally think the video came out very visually interesting, artistic, and satisfying.

References

Music Rights: *Youtube Media Library*

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