TEAM SECOND

MCEN 5151: Flow Visualization

Author/Photographer: Monica Luebke

Collaboration: Avery Fails, Sarah Hartin, and Izzy Young

November 10, 2023

Image Intent

For the second team photo, my group chose to experiment with edible glitter to demonstrate a rheoscopic fluid. The artistic intent was to capture the glittering sparkles in a fluid mixed with alcohol. While I didn't capture the sparkles, I think the color from the edible glitter and the blurred "focus" of the edible glitter assisted in the visual appeal of the image. Throughout the experiment, I found that the edible glitter created such a viscous liquid that it was difficult to disturb the fluid and then capture a photo in focus. I initially intended to create an image that captured the vortices created while a motion of the fluid was obstructed by an object. The focus was too difficult so instead I ended up just creating a circular flow of fluid and capturing an image that way. The scientific intent of this experiment was to test and analyze the behavior of rheoscopic fluids.

Image Description

Figure (1) below shows the diagram to recreate this image. This set up is pretty simple and doesn't require too specific of measurements in order to recreate the flow. A mixture of approximately 6 ounces of water, and a three second pour of Underwood Rose Bubbles, and 4 large pinches of the Muloen Edible Glitter-Purple were added to a cup sitting on a table. The cup dimensions were 3.5 inches in diameter and a height of 4.75 inches. A straw mixed the solution quick enough to create the rotational vortex depicted in the image. The camera was positioned about six inches above the glass to take an aerial shot of the fluid flow. This image was taken in the Integrated Teaching and Learning Laboratory (ITLL) on the University of Colorado Boulder's campus. Generic classroom overhead lighting provided the necessary illumination for this image. The specifics on the type of installed lighting in the study room are unknown. Team member collaboration included Izzy Young, Sarah Hartin, and Avery Fails.

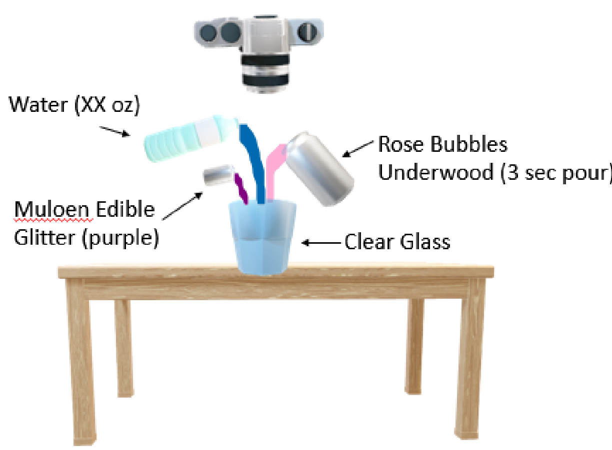

Figure 1: Set Up for Fluid Flow Experiment (NDTS)

The original size of the photo was 6016 x 4016 pixels for a total RAW file size of 22.8 MB. Figure (2) is the original, unedited photo.

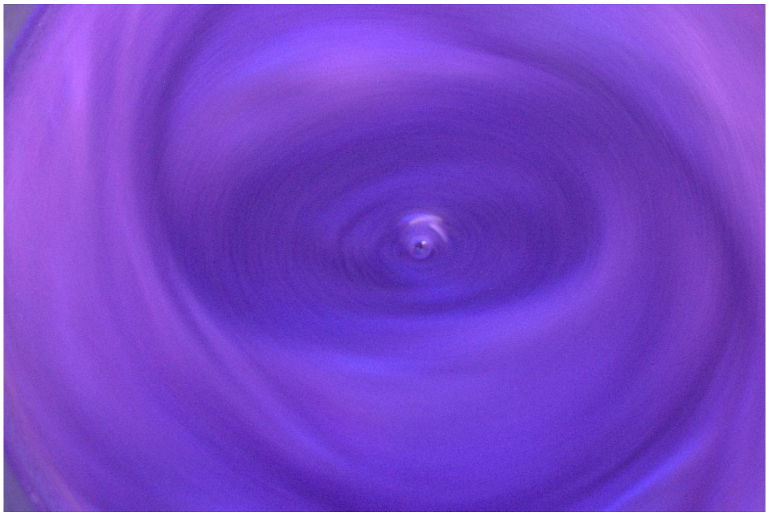

Figure 2: Original, Unedited Image

Table (1) below indicates the parameters recorded from the camera for the capture of the image. The spatial resolution for this image was on an order of 2. The field of view was 7.5 inches, which was then used to calculate the time resolution value. The final image does not have any time resolution; the calculations support that the fluid was moving at 7.05 in/s which is typically much faster than preferred to consider time resolution. However, I did not expect this calculation to result in an acceptable time resolution value due to the nature of the image. Instead, this image has time averaging which is what produces the blurred motion effect of the fluid vortex. (Hertzberg, n.d.)

Table 1: Image Characteristics

Camera	Nikon D5500
Lens	Nikkor 18-55 mm 1:3.5-5.6G DX VR
Focal Length	48 mm
Aperture	f/5.6
Shutter speed	1/13
ISO	200
Other	Manual focus

Image Editing Process

Darktable, an editing software program, edited the photo from Figure (2) to get the resulting image seen in Figure (3) below. This image was cropped and compressed to 5541 x 3626 pixels for a file size of 29.2 MB. I chose this cropping selection to remove the edge of the glass in the top left corner from the original image. The first editing step in Darktable adjusted the RGB curve to alter the coloring slightly. The second step decreased the shadows to a -55.64 to make the center darker and draw the human eye towards the center of the image where the bubble resides. The contrast was the final editing step in this process to really amplify the galaxy looking vibe of the image.

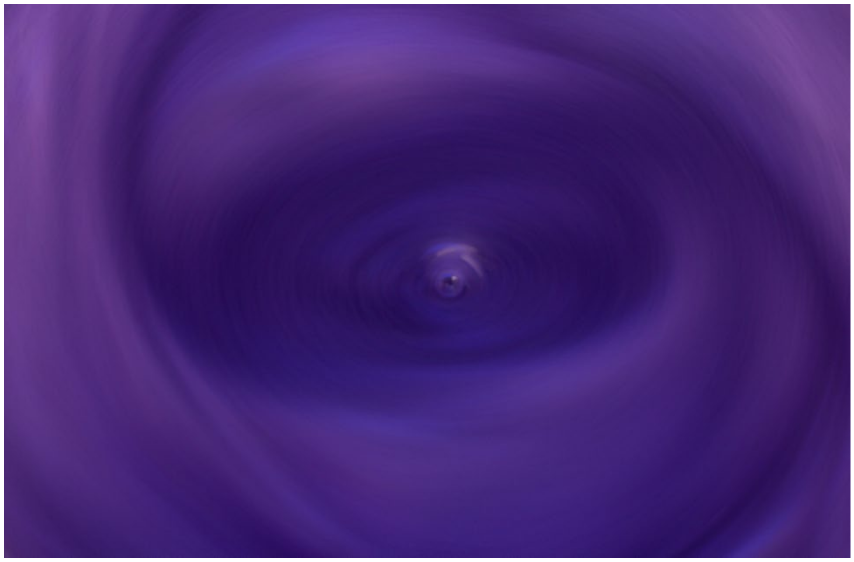

Figure 3: Final, Edited Image

Fluid Flow Phenomena

This project used edible glitter to mimic a rheoscopic fluid. "Rheoscopic fluids are a common technique for visualizing spatially extended flow structures…the working fluid is seeded with small, anisotropic, reflective particles" (Borrero-Echeverry, Crowley, & Riddick, 2018). Rheoscopic fluids are an excellent method to demonstrate vortices and general fluid flow (laminar verse turbulent).

This experiment addresses two physics concepts within the rheoscopic fluid phenomenon; a suspension fluid and a rotational fluid. One distinguishing feature of a suspension is the size of the particles; glitter particles are typically around 250 micrometers, which converts to 250,000 nanometers (nm), and resemble a hexagonal shape. (Burt, 2019) Suspensions contain particles greater than 100 nm in size, making this experiment a suspension vice a colloid which is typically between 1 and 100 nm. (Bozhilova, 2018) Suspension is a heterogeneous mixture, meaning that the elements within the mixture can be separated if left undisturbed for some time. The insoluble particles, in this case the glitter, begin to settle while the fluid was not actively being mixed; however, when the straw performed the mixing of the fluid, the glitter particles remained suspended throughout the fluid. (Bozhilova, 2018) "In a viscous liquid, one layer exerts more drag on its neighbor, producing a thicker fluid that is more resistant to deformation and flow. Particles in a suspension behave in a similar manner" (Tasoff, 2022) By adding the edible glitter to the fluid, the viscosity significantly increased which made the image difficult to capture because when the disturbance of the straw, which was creating the rotational vortex, was removed, the particles of the glitter resisted the flow and the circular motion ceased.

A rotational vortex "is a special form of fluid motion featured as the rotation of fluid elements and is ubiquitous in nature." (Tian, Gao, Dong, & Liu, 2018). A familiar example of this phenomena is a hurricane or a tornado. The units of the edible glitter rotated about an imaginary axis which is located at the "bubble" in the center of the photo. The vortex vector is the rotational part of the vorticity which helps define the local rotation of the fluid. (Tian, Gao, Dong, & Liu, 2018) The glitter particles aligned with one another and traveled as one unit around the axis which is what created the circular flow seen in Figure (2).

The Strouhal number is a nondimensionalized value that describes “the oscillations of the flow due to the inertial forces relative to the changes in velocity due to the convective acceleration of the flow field” (Katopodes, 2019). Convective acceleration is the acceleration of a particle as it moves throughout the fluid to a different part of the flow. (Material Acceleration, n.d.) Equation (1) identifies the Strouhal formula (Katopodes, 2019) below:

$$S_{tr} = \frac{fL}{u} \qquad \text{Eq. (1)}$$

Where f = frequency of oscillation (1/T)

L = characteristic length

u = flow velocity

The characteristic length for this experiment was the diameter of the cup, the frequency of oscillation was determined through an estimation by a video taken on the same day of the experiment, and the flow velocity was assumed to be the same as the aforementioned time resolution value. By plugging these values into the equation, the results yield the following:

$$S_{tr} = \frac{fL}{u} = \frac{\left(4\frac{oscillations}{\sec}\right)*(3.75\ in)}{7.05\frac{in}{\sec}} = 2.12$$

This value, of 2.12, is larger than one would typically expect for this nondimensional value; however, due to the assumptions and the scaling of the inputs, this number is considered acceptable. Strouhal numbers on the order of one identifies that viscosity is the main driver of the fluid flow which conceptionally makes sense as the addition of the edible glitter simultaneously increased the viscosity and the resistance to flow without an external disturbance. (Bartmess, 2015) The Strouhal value indicates a period verse a time to travel a given single length distance. The higher the Strouhal number, the higher the ratio of the number of oscillations when compared to the change in velocity of the fluid and particles.

Conclusion

While the final image was not the intention at the start of this experiment to demonstrate a rheoscopic fluid phenomenon, I think the end result was unique and different. The motion blur provided a sense of dramatic effect. The final image resembled inner galactic vibes. The bubble in the center of the image was a coincidence, but I do like it because I think it draws the eye to follow the vortex into the center of the image. I think this image displays more photographic techniques than it does the physics. In the future I would spend more time with the set up and use a tripod to hold the camera steady while using an artificial external light to add more background lighting in hopes to increase the shutter speed so the individual particles of the glitter could be captured in the image. Then, in theory, the vortices following an obstruction placed in the path of the vortex could be further and more articulately analyzed. The effect of highly viscous fluids provided a challenge when photographing. The particles were resistant to flow in the rotational vortex if not constantly disturbed by the straw. I learned to like the image the more I looked at it and began to read up on the different fluid flow topics displayed in the image.

Collaboration

Avery Fails, Sarah Hartin, and Izzy Young

References

Bartmess, M. (2015, March 11). *Stouhal Number* . Retrieved from vCalc: https://www.vcalc.com/wiki/MichaelBartmess/Strouhal-Number

Borrero-Echeverry, D., Crowley, C. J., & Riddick, T. P. (2018, August 23). Rheoscopic fluids in a post-Kalliroscope world. *Physics of Fluids , 30*(8). doi:https://doi.org/10.1063/1.5045053

Bozhilova, M. (2018, May 29). *Difference Between Colloid and Suspension*. Retrieved November 5, 2023, from Difference Between Similar Terms and Objects: http://www.differencebetween.net/science/difference-between-colloid-and-suspension/

Burt, J. (2019, December 24). *Is the Glitter on your Christmas Cake Edible?* Retrieved from Malvern Panalytical : https://www.materials-talks.com/is-the-glitter-on-your-christmas-cake-edible/

Hertzberg, J. (n.d.). *Overview 4 – Photography E – Resolution*. Retrieved November 5, 2023, from Flow Visualization: https://www.flowvis.org/Flow%20Vis%20Guide/overview-4-photography-d-resolution/

Katopodes, N. D. (2019). Chapter 5-Viscous Fluid Flows . In N. D. Katopodes, *Free-Surface Flow Environmental Fluid Mechanics* (pp. 324-426). doi:https://doi.org/10.1016/C2016-0-04780-0

Material Acceleration. (n.d.). Retrieved November 6, 2023, from https://www.me.psu.edu/cimbala/Learning/Fluid/Material_Acc/material_acceleration.htm#:~:text=The%20last%20three%20terms%20make,even%20in%20a%20steady%20flow!

Tasoff, H. (2022, April 7). Engineers describe how fluid suspensions exhibit different behaviors at different scales. *PRoceedings of the National Academy of Sciences*. Retrieved from https://phys.org/news/2022-04-fluid-suspensions-behaviors-scales.html

Tian, S., Gao, Y., Dong, X., & Liu, C. (2018, June 18). Definitions of vortex vector and vortex. *849*, 312-339. doi: https://doi.org/10.1017/jfm.2018.406