Vortex Rings and Trails of Food Coloring in Water

Image-Video 3

MCEN 5151-001

University of Colorado Boulder

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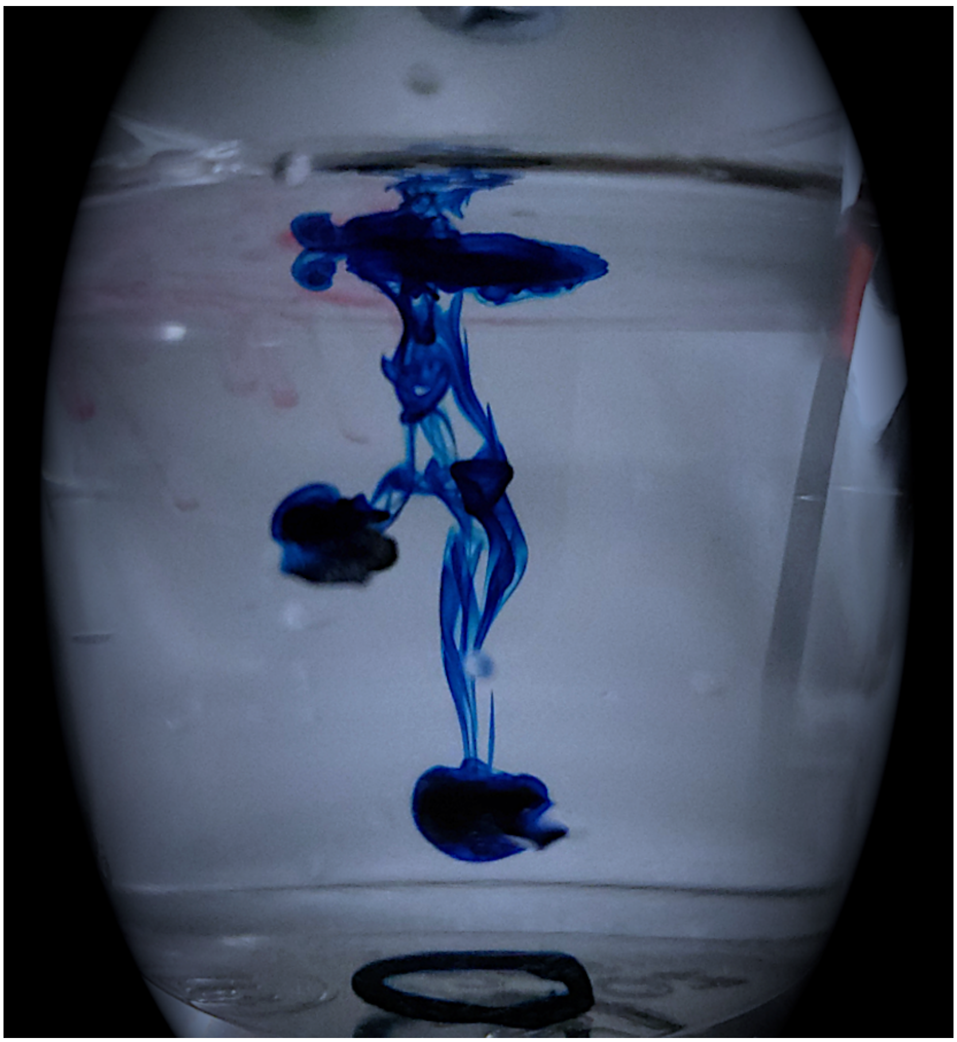

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Introduction:

For the third image-video assignment, the goal was to take a picture or video that demonstrates a phenomenon being observed and is a good picture or video. The phenomenon shown in this image is a vortex ring and trails following a drop of food coloring as it diffuses. To visualize this phenomenon, a picture was taken to capture two different drops of blue food coloring into a clear, plastic cup of water.

Physics and Flow:

The flow apparatus used in this image is demonstrated in figure 1. An empty cup was filled with tap water until it was nearly full (roughly half an inch from the top). Once the cup was filled, it was placed in front of white fabric taped to a wall for a more solid background.

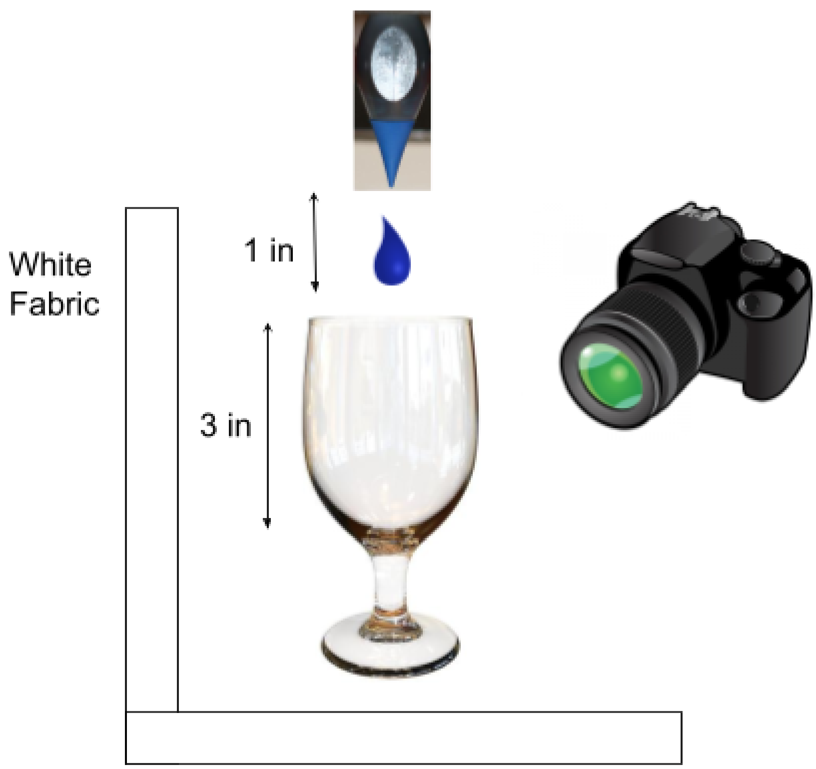

Figure 1: Flow Apparatus

The phenomenon occurring here is a vortex ring as seen towards the bottom of the cup in the final photo as well as the diffusion of food coloring in room temperature water. First of all, the vortex ring is the cause of low Weber numbers where “the total amount of vorticity generated depends on the quantity which can be diffused into the fluid interior from the boundary during coalesence.” [1]. The Weber numbers tell us “whether a condition appears to be sufficient to generate enough vorticity to allow flow separation at the surface.” [2]

While experimenting to take a photo of this phenomenon, it was noted that these vortex rings did not occur in every instance. In fact, they only occurred when the food coloring was dropped at a low height. The speed at which the food coloring drops into the water also changed whether or not the drop would turn into a vortex ring. As seen in the final photo, the first drop was the vortex ring at the bottom of the cup, and the second drop was dropped at a much greater velocity which caused the drop to diffuse instead. Based on these observations, the first drop would expected to have a small Weber number while the second drop would be expected to have a larger Weber number

The Weber number is the ratio of the time for the drop to diffuse due to surface tension to the time it takes for the diameter of the drop to change. Based on the formula [3]:

$$We = U(\frac{\rho D}{T})^{\frac{1}{2}}$$

The Weber consists of U (velocity), D (diameter), ρ (density) and T (surface tension). From inspection of this equation, both drops are assumed to have very similar surface tension and density since both drops are made of the same liquid. The diameter of the first drop and second drop might have been slightly different mainly due to the inconsistency of the squeeze of the bottle to drop the food coloring. However, it is not expected that the diameters would be too different considering the overall scale of a single droplet. Lastly, the variable that had the biggest change to the Weber number of the droplets came from U, the velocity of the water droplets. The first drop was the result of a light squeeze on the bottle and the second drop was from a harder squeeze. Based on the amount of force applied to the bottle, the velocity of the drops exiting the bottle was directly proportional thus the second drop must have had a larger velocity resulting in a larger Weber number. From this inspection, it can be concluded that the Weber number of the second drop is much greater than the Weber number of the first drop which resulted in the first drop creating a vortex ring and the first drop simply diffusing.

Visualization Technique:

The visualization technique used was squeezing a bottle of Watkins no artificial blue dye into a clear, plastic cup of room temperature tap water in Boulder, Colorado. The clear cup was only 3.5 inches in width and 3 inches in height and could only hold 9 oz of water. The cup was placed onto white fabric for a more stable and clear background. The lights in the room were completely off, and the photo was taken at night so no sunlight would interfere with making the scenario pitch black. The main source of light came from an LED light ring placed to the right of the cup. The food coloring was dropped roughly one inch above the surface of the water which was roughly half an inch from the top of the cup.

Photographic Technique:

Similarly to the first to image-video projects, the field of view was again one of the first techniques considered. Because the drops of food coloring were extremely small within the already small cup, the distance from the cup to the camera lens was around 2 to 3 inches away. This distance was ideal because it allowed the camera to focus on the drops. However, even with the camera this close, there were still some distractions around the apparatus that needed to be removed with post-process. Zooming in with the camera would only blur the photo even more, so Vignette in Gimp was used to center the attention on the food dye in the cup using the settings shown in figure 2.

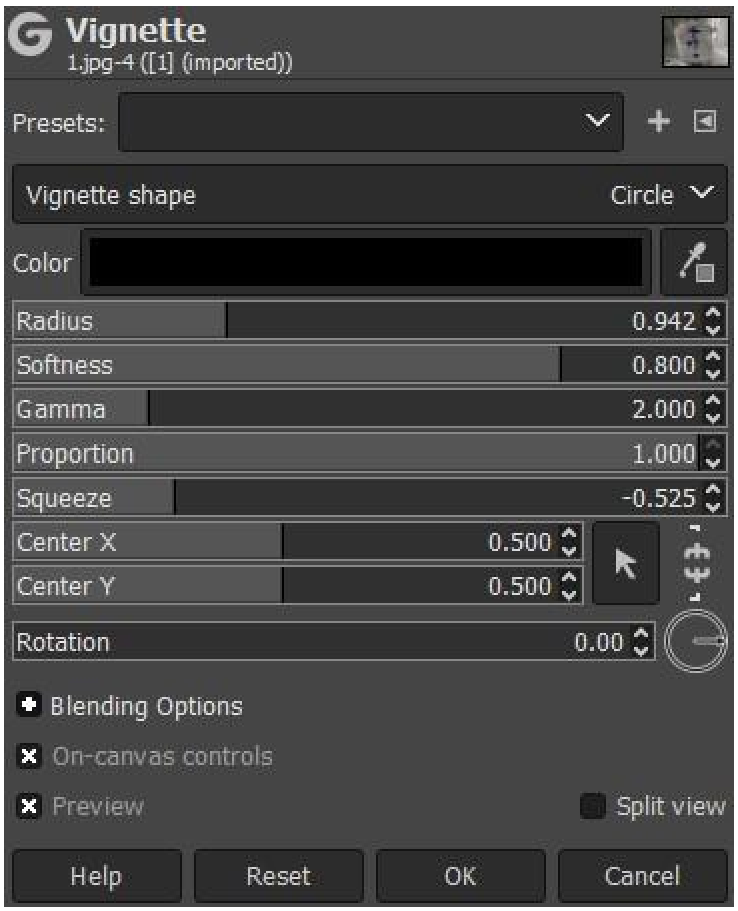

Figure 2: Gimp Vignette Settings

The camera and settings were as followed:

Camera:	Samsung Galaxy S9
Aperture:	F/1.5
Exposure:	1/1000s
Focal Length:	4.30 mm
ISO:	800
Width:	4032 pixels
Height:	3024 pixels

The type of camera was a phone camera because it was convenient and still had decent picture-taking capabilities. The aperture was set to f/1.5 to allow more exposure to light since the picture was being taken in the dark. Any light apart from the light from the computer and light ring gave the photo an unbalance in color, so all external lights and flashes were turned off. The exposure was set to 1/1000s to capture the vortex ring of the food dye since it did not last long enough to take multiple pictures of and because the fluid is moving so a finer exposure would be able to capture more. The ISO was set to 800 to allow more sensitivity to light to make the picture brighter. The ring light were bright enough to be able to increase the exposure as well. Lastly, the final image width and height were 4032 and 304 pixels respectively. This width and height were the best setting for the Galaxy S9 because it allowed it to take a 12 MP picture which was the highest it was capable of.

The other post-processing used on this image was sharpening to make up for any blurriness and some minor changes in the background color to make the blue dye stand out more. The settings for the sharpening in Gimp can be seen in figure 3.

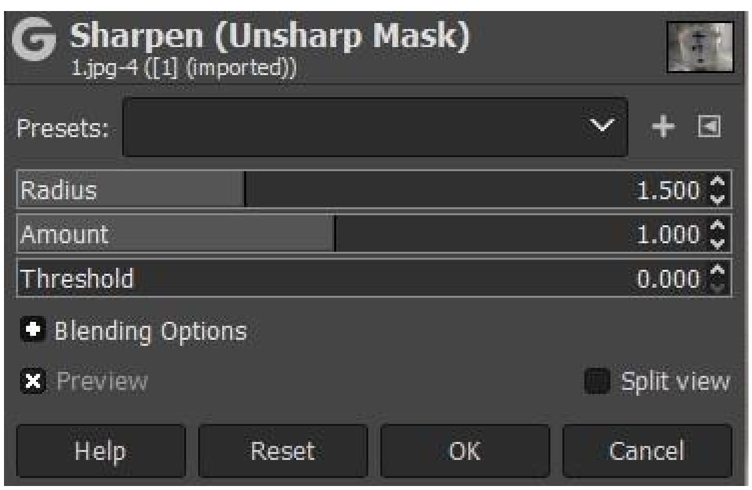

Figure 3: Sharpen Settings in Gimp

Conclusion:

The image showed food coloring creating a vortex ring in a cup of tap water and also diffusing based on the speed at which it entered the water. Although this phenomenon did not occur constantly or very long, it was very intriguing and awe-inspiring to me when I was able to capture the moment it specifically create a vortex ring. Something I did not like about the image was the random smudges of water around the cup. I must have not paid much attention to the cup after wiping it after every trial. Luckily, the smudges do not take away too much from the purpose of the image and if given more time, I would have tried to clear up those smudges using Gimp or some sort of post-processing. I also would have loved to have tried this experiment with different colors of food dyes to make the color of the photo stand out more rather than just having one color as the center of attention.

References

[1] Cresswell, R. W., & Morton, B. R. (1995). Drop‐formed vortex rings—The generation of vorticity. *Physics of Fluids, 7*(6), 1363-1370. doi:10.1063/1.868524

[2] Hsiao, M., Lichter, S., & Quintero, L. G. (1988, December 01). The critical Weber number for vortex and jet formation for drops impinging on a liquid pool. Retrieved from https://aip.scitation.org/doi/10.1063/1.866872

[3] Weber Number. (n.d.). Retrieved from https://www.sciencedirect.com/topics/chemistry/weber-number

Appendix