Flow Visualization: Get Wet

MCEN 4151: Flow Visualization

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Demonstrating the Rayleigh – Taylor instability by dropping red, yellow, and blue ink into water simultaneously.

Purpose

The purpose of this assignment was to “get your feet wet” and begin experimenting with flow visualization techniques. The requirements of this assignment were to make a good picture of fluids that demonstrate a phenomena being observed. For the purpose of this lab, the project chosen was dropping red, yellow, and blue ink into water simultaneously to observe and capture the Rayleigh-Taylor instability. The intent was to observe this phenomenon as well as capture a multi-colored, interesting image of a fluid flow.

Flow Apparatus

The experiment was performed in a rectangular flower vase. This container was chosen to make the photo as the flat surface of the container would likely not distort the phenomenon as compared to a circular container. The height of the container used was 10 inches filled with 9 inches of room-temperature water. The ink used resembles food coloring that can be purchased at a grocery store but is actually Batik ink that is used to dye cloth. The red, yellow, and blue inks came in small dropper containers making it easy to use. It is important that the ink or dye is dropped into the water in small quantities to observe the Rayleigh-Taylor instability properly and for that reason only one droplet of each color was used. The diameter of the droplets is roughly 4 millimeters wide which proved to be more than enough width for this experiment. The droplets were also released only about 2 centimeters above the surface of the water to avoid excessive splashing of the ink before submerging in the water.

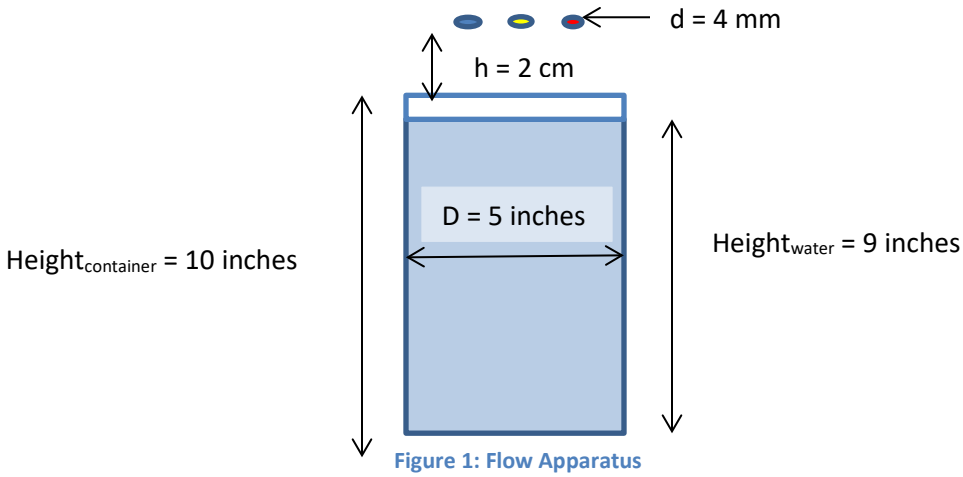

Figure 1: Flow Apparatus

Flow Dynamics

The first effect that can be observed through this experiment is a vortex ring. After the ink droplet leaves the dropper container and hits the water, it is no longer a 4mm sphere of ink and begins to expand as it sinks through the water. The ink sinks through the water fairly quickly due to the fact that the ink has a higher density than the water. The sphere of ink appears to be expanding in the glass because it is actually dispersing. The expansion is in the form of a ring

and this is known as the toroidal vortex ring. The reason for the shape of the ring is because the sides of the ink are getting pushed upward as the rest of the droplet is still falling through the water. However, this phenomenon does not last long as the droplet eventually becomes unstable. When the droplet becomes unstable, the Rayleigh-Taylor instability can be observed and captured for this photo. The Rayleigh-Taylor instability is a beautiful phenomenon as it appears as umbrellas branching out in the water. This is because the drop has become turbulent in the water. Laminar and turbulent flow can be characterized by the Reynolds number. The Reynolds number can be calculated as seen below:

$$Re = \frac{UD}{v} = \frac{\left(0.1\frac{m}{s}\right) * (0.004m)}{1.004 * 10^{-6}\ \frac{m^2}{s}} = 398$$

In this equation, the velocity of the droplet (U) was estimated to be 0.1 m/s, the diameter (D) of the droplet was stated above as 4 millimeters and the viscosity of water at room temperature, approximately 20 degrees Celsius, is 1.004*10^-6 m^2/s. The number achieved from this equation represents the laminar flow shown by the vortex ring effect. However, when the droplet starts forming the unstable umbrella shapes, this is an obvious characteristic of turbulent flow. The Reynolds number for this Rayleigh-Taylor flow would therefore be much higher; however, the diameter and velocity of the drop is difficult to approximate in this stage of the flow.

Visualization technique

Red, yellow, and blue ink was chosen to achieve a more interesting, multi-colored picture with an artistic appeal; however, this experiment could be performed using just one color of ink or food coloring. The apparatus setup is important to have ready before taking photos in this experiment as the photos need to be taken only one or two seconds after the ink has been dropped in the water. If the photographer waits too long to take the photo, the ink will have dispersed too much and the water will become murky. For this reason, only one drop of each color of ink should be used. Because the lighting was hand held, there were three inks dropped into water simultaneously, and the photo needed to be taken, there were two people involved in this experiment. Person A dropped all three inks into the water and then quickly grabbed the lighting while Person B focused on shooting the image.

In this setup, a white background was used. This was achieved by placing plain white paper behind the rectangular container. The container was set on the kitchen counter as to provide a flat and stable surface for working. The problem occurred that using the flash would cause reflections off the glass container as well as using the overhead canister lighting in the kitchen.

For this reason, the lights in the room were turned off and an LED flashlight was held over the container with a paper towel placed over it as to diffuse the lighting and avoid reflections. The camera was then placed about 5 inches from the side of the tank. This setup can be seen in the diagram below.

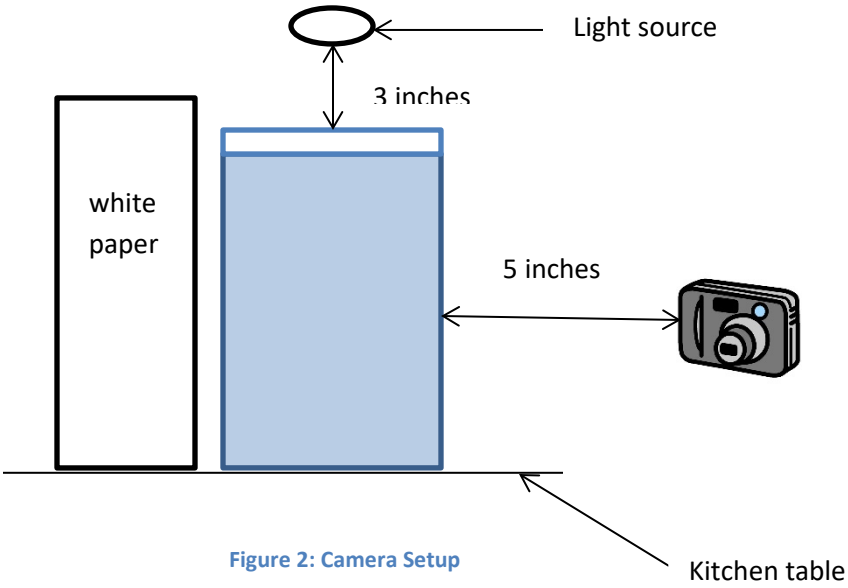

Figure 2: Camera Setup

Photographic Technique

The camera used in this assignment was a Sony Alpha a5000 mirrorless digital camera with mounting capabilities for a manual focus lens. The lens used on this camera was a 16 – 50 millimeter lens and the lens focal length was at 42 mm for this image. The aperture used for this photo was F22. This small aperture was used to focus on the flow via depth of field seeing as the difficulty arose with the camera focusing on the container or surface bubbles of the water on the container. Because of this small aperture, a longer shutter speed (1/13 second) was used to allow enough light for the image to come across clearly. An ISO of 3200 was used to obtain enough information without too much noise in the photo. These settings in addition to the setup described earlier and the exemption of the flash led to the photo in figure 3 below.

Use of an open – source photo editing program Gimp was then used to create the final image. The image was cropped to focus on the colored portion of the image then contrast and brightness were adjusted since the original image is a little dark. Furthermore, the color curves were adjusted to make the image appear to have even more contrast and brightness. The post – processing after image is also shown below in figure 3:

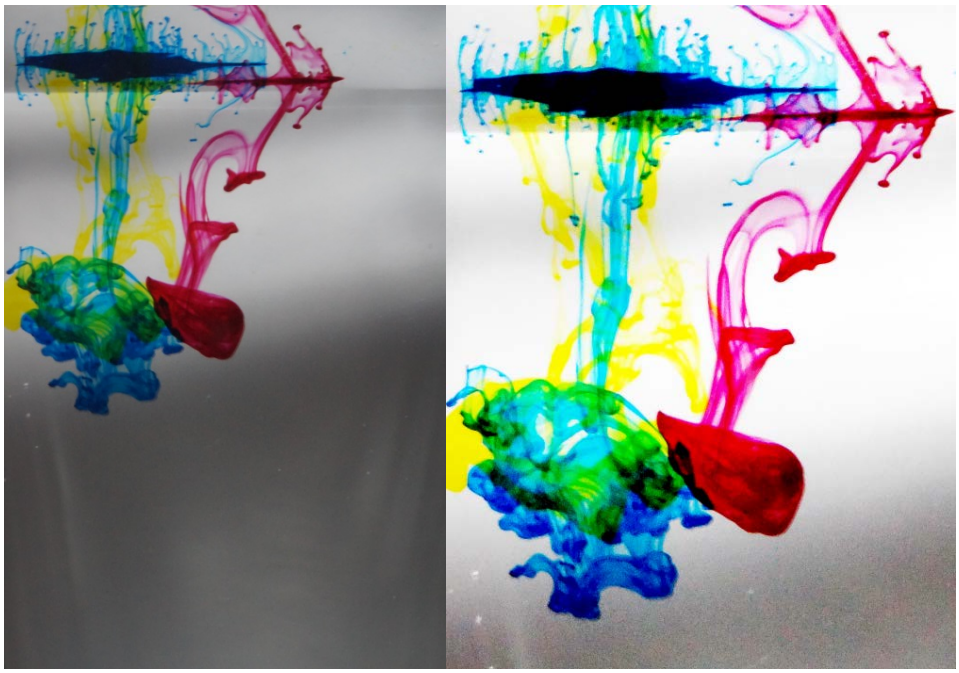

Figure 3: Raw image (left) and processed image (right)

Conclusion

The project was a great success in terms of really experimenting and understanding flow visualization techniques. There were various attempts on this project which resulted in understanding the camera, settings, and how settings affect photos. Image manipulation through Gimp was explored. Furthermore, this experiment also proved the importance of having a good apparatus and flow setup to achieve an interesting image but most importantly, fluid flow concepts were explored to understand what was actually happening in the image.

The image revealed important fluid concepts in an artistic and colorful way. I really enjoyed the yellow ink overlapping the blue ink to form green pops of color even though there was not green ink in the image and the inks did not mix. However, I realized later on that my image appeared grainy and I would prefer less motion blur. To correct this next time I would probably use a slightly lower ISO to clean-up some of the noise as well as utilize manual focus more instead of the depth of field technique that was used. However I really enjoyed the fact that the red ink fell into the tank later than the yellow and blue because I was able to capture different stages of the Rayleigh-Taylor instability in the same photo. I feel like because of this, I fulfilled my intent with this photograph in demonstrating fluid flow but need to work on the photography aspect more. If I were to develop this idea further, I would get a much bigger tank and experiment with trying to capture various levels of laminar and turbulent flow in the same image by having different inks enter the water with different velocities and maybe through different dropper containers of various diameter openings.

References

1. https://en.wikipedia.org/wiki/Rayleigh%E2%80%93Taylor_instability
2. https://en.wikipedia.org/wiki/Vortex_ring
3. http://www.sony.com/electronics/interchangeable-lens-cameras/ilce-5000-kit