Get Wet Image Report

MCEN 4151 Flow Visualization

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Introduction

This image is for the Get Wet assignment in Flow Visualization. The overall goal of the assignment is to create a picture or a video of any fluid phenomena and gain experience in visualizing fluid flows. For this assignment, I worked with Kristopher Tierney and Stephen Wong to show the instabilities that occur when food dye and water are mixed. I was interested in photographing food dye in water, because I had seen picture of it elsewhere and liked the instability patterns. My partners and I collaborated to set up the experiment and tried many different colors and combinations of food dye. Then, we each selected the image that we liked best and post processed it individually.

Experiment and Flow Description

The experimental set up is shown in Figure 1. The details in the flows were small, so the camera was placed close to the glass vase. The lens was approximately 5 cm from the front of a glass vase, and the focus was set to the shortest possible focal length (4 mm). The vase held approximately 16 cm of cold water vertically, and it was 4.2 cm in diameter. The food dye was dropped into the water from a few centimeters above the top of the vase. A computer screen was placed 20 cm behind the vase and set to display a pure white screen with maximum brightness. This screen provided a uniform backlight to better visualize the colors in the vase. The vase was placed on a cardboard box to elevate it about 4 cm so that the camera was pointing at the water just below the surface. See Figure 2 below.

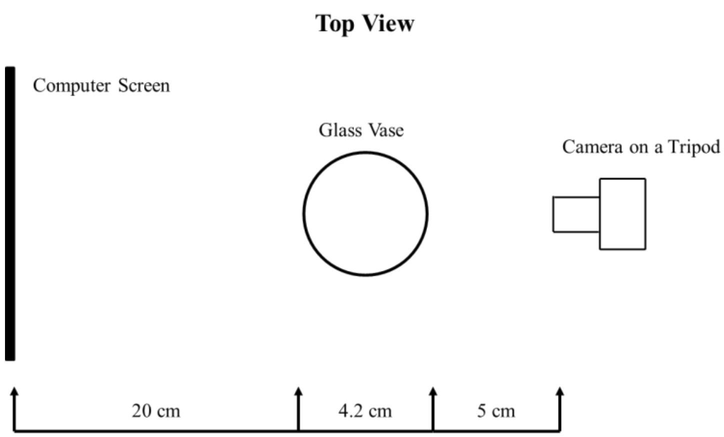

Figure 1: Experiment Sketch

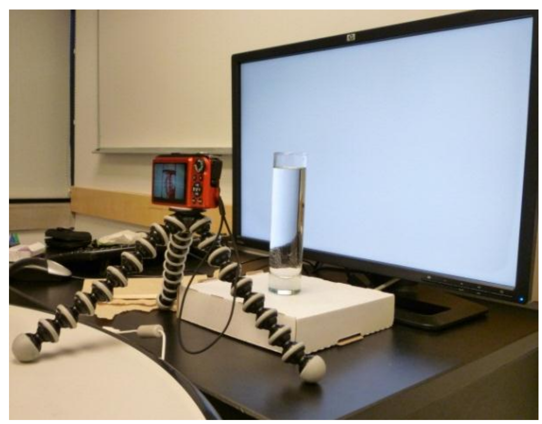

Figure 2: Experiment Setup

Several images were taken with a variety of dye colors and combinations. For this image, one drop of red food dye and one drop of blue food dye were dropped simultaneously onto the surface of the water in the vase. This color combination was chosen, because the red dye and the blue dye provided the most vibrant colors, which contrasted with the white background. Only one drop of each color was added, because each drop became a single plume. After taking many pictures, images with one or two color plumes had better composition, than those with more plumes.

The addition of the food dye created an unstable interface between the two fluids, because the denser food dye was located in a layer above the less dense water[1]. Gravity is the primary force driving this fluid flow, and it causes the denser food dye to form plumes as it sinks in the water. This action is known as Rayleigh-Taylor instability. As the instabilities evolve, the simple plumes branch out forming other features, such as bags, veils, or curtains instabilities.[2] It is at this stage that the image was taken. The blue dye plume on the left side of the image shows a veil as a branch splits into smaller branches. The red dye plume on the right side shows a swirl that formed in one of the branches. This branch was moving from right to left as it fell towards the bottom of the vase, and the conditions were just right for the swirl to form. Both of the plumes are about 1 cm across.

The minimum shutter speed required to eliminate motion blur can be estimated from this image. It is assumed that a motion blur of 5 pixels or less is acceptable, and 5 pixels can be converted to meters with the following equation.

$$displacement = \frac{(field\ of\ view)(accepable\ blur)}{height\ of\ image} = \frac{(0.056\ m)(5\ px)}{3000\ px} = 9.3 * 10^{-5}\ m$$

The velocity of the fluid varies throughout the image, so the velocity and motion blur are calculated for the branch that produced the blue veil. Several images were taken as the blue and red dyes mixed with the water. By comparing how far the veil fell and the number of pictures per second that the camera can take (2 pictures/second), the velocity of the veil was determined to be $0.003\ m/sec$. The veil's velocity can be used to calculate the required shutter speed.

$$speed = \frac{displacement}{velocity} = \frac{9.3 * 10^{-5}\ m}{0.003\ m/sec} = \frac{7}{225} = 0.0311\ seconds$$

The minimum shutter speed required to eliminate motion blur is 0.0311 seconds. A shutter speed of 1/2000 seconds was used in the image, so virtually all motion blur was eliminated around the blue veil.

The Atwood number is a ratio of the densities of the fluid in the mixture, and it is related to the growth rates of the Rayleigh-Taylor instabilities. Performing a similar experiment with fluids that have different densities (and therefore different Atwood numbers) will result in different growth rates for the Rayleigh-Taylor instability plumes.[3] The Atwood number for the flow around the blue veil is calculated with the following equation.

$$A = \frac{\rho_1 - \rho 2}{\rho_1 + \rho 2}$$

Here $\rho_1 = 1003\ kg/m^3$ and represents the density of the food dye at room temperature.[4] $\rho_2 = 1000\ kg/m^3$, and it represents the density of water at room temperature.

$$A = \frac{1003 - 1000}{1003 + 1000} = 0.00150$$

This is a relatively small Atwood number,[5] because the veils tend to form for Atwood numbers approximately less than or equal to 1.[6]

The Reynolds number is a ratio of the inertial forces to the viscous forces in a fluid, and the Reynolds number can be estimated for the dye in the blue veil. The density of the dye is $\rho_1 = 1003\ kg/m^3$,[7] and the velocity of the dye is $0.003\ m/sec$ as calculated above. The dynamic viscosity of the dye is assumed similar to the McCormick dye used by Fuerstman et al with a value of $0.011\ Pa * sec$.[8] The characteristic diameter was taken to be the horizontal length of the veil, which measures $0.016\ m$ across. Using these values, the Reynolds number can be calculated with the following equation.

$$Re = \frac{\rho_1 * V * D}{\mu} = \frac{(1003\ kg/m^3)(0.003\ m/sec)(0.016\ m)}{0.011\ Pa * sec} = 4$$

This Reynolds number is a relatively low Reynolds number, so the effect of the viscous forces is similar to the effect of the inertial forces. This produces a laminar flow near the blue veil with minimal mixing and turbulence. In the image, the red and blue dye plumes have not mixed significantly since they were dropped into the water, so it is expected that the Reynolds number is small. However, some mixing is present in the image. The red swirl shows that there is some rotational motion caused by shear as the red branch moves from right to left, and this region likely has a higher Reynolds number than the region with the blue veil.

Visualization Technique

The bright colors of the food dye illustrate the Rayleigh-Taylor instability. The food dye is a traditional food dye used in cooking, and it was purchased at a local grocery store. The food dye was dropped into cold water taken from a water fountain. As the water warmed up to room temperature, air bubbles formed on the inside of the glass vase. These were distracting to the flow visualization, so they were removed with a popsicle stick just before the food dye was added. The entire experiment was done indoors, so the air around the vase was still. The vase was made of clear glass and had a diameter of 4.2 cm. It was also 19 cm tall.

The image was taken in a dark room with a computer screen acting as the single source of light. The computer screen was a large monitor that was set to maximum brightness and displayed a pure white screen. The monitor was positioned about 20 cm behind the vase and perpendicular to the camera lens. No flash was used.

Photographic Technique

The image was taken with a Canon PowerShot SX280 HS Digital Camera with 12.1 megapixels. The camera lens has a 4.5 - 90.0 mm focal length and a 20 times optical zoom with image stabilization. It can produce an aperture between 1:3.5 and 1:6.8, and the camera supports an ISO from 80 to 6400.

The original image was 4000 by 3000 pixels with a bit depth of 24. I was interested in having a crisp image that minimized motion blur, so the shutter speed was set to 1/2000 seconds. Since the room was dark and the shutter speed was fast, the ISO was set high at 3200, and a low F Number of 3.5 was used. The low F Number also contributed to the clear, crisp image throughout the vase. For this image, the focal length was 4 mm.

To image the food dye, the vase was placed about 5 cm from the end of the lens. Since the diameter of the vase is 4.2 cm, this arrangement produced a field of view of about 8 cm by 5.6 cm for the original image. The final image was cropped to improve the composition and to remove the unnecessary background with Adobe Photoshop (CS6). This produced an image that was 1976 by 2575 pixels resulting in a field of view of about 4 cm by 5 cm. The original image was dark overall, so the contrast was increased with the Curves Tool in Photoshop to brighten it.

There were also a few spots and air bubbles on the inside of the vase that detracted from the physics of the mixing fluids, so the Clone Stamp Tool was used to remove them. See the original image in Figure 3 below as a comparison.

Figure 3: Original Image

Image Results

This image provides a beautiful and graceful illustration of the Rayleigh-Taylor instabilities that occur when food dye is placed in water. I chose this image from 140 other images that were taken, because I like red swirl. The swirl's creation was unexpected but greatly enjoyed. It reminds me of a rose.

The goal of this image was to produce a clear and focused shot of food dye mixing with water. I am satisfied with the result, and the high shutter speed that I used minimized the motion blur. Since the original image is backlit by a single source of light, it is dark overall. In the future, it would be helpful to try different lighting arrangements. Backlighting the food dye helps highlight the colors, but adding additional sources around the vase of the camera could brighten the entire image.

If the image were brighter, a smaller aperture could be used. This would increase the depth of field and make the image less flat. This could be done in an interesting way. One could try dropping three different colors of food dye in the water: one color near the front of the glass, one color near the middle of the glass, and one color near the back of the glass. By focusing on the middle color with a smaller aperture, one could see a cool effect of the three colors through the depth of field.

References

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