

Flow Visualization: Get Wet



MCEN 4151: Flow Visualization
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Purpose

An easy way to acquire colorful and complex visualizations of fluid flow is to use the assistance of food coloring. The success of capturing a good representation of fluid flow relies on visualization and photographic techniques. For this image several techniques were used to obtain a visually pleasing portrayal of the toroidal effect and the Rayleigh-Taylor instability.

Flow Apparatus

The most accessible and effective container to use for this image is a clear glass with very little detail. This image was taken using a tall shot glass (approx. 20 centimeters) filled with 15 centimeters of water. The food coloring can be purchased from most grocery stores. The typical dye colors are green, red, yellow, and blue; and they come in dropper containers. It is important not to use too much dye when attempting to create this phenomenon. The droppers create droplets with a diameter of 3 millimeters, and one droplet for each dye is plenty. The photographer should experimentally determine which combination of dye colors should be used. The image displayed uses blue and red dye dropped into the glass of water roughly 2 seconds apart. Each droplet is released about 1.5 centimeters from the water's surface. The water was at room temperature.

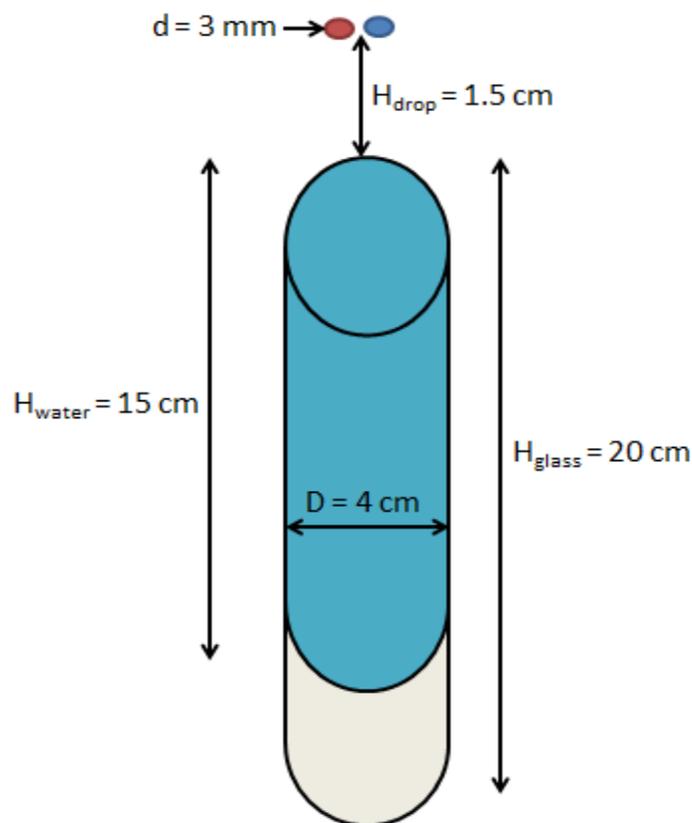


Figure 1: Flow Apparatus

Flow Dynamics

After the droplets are released into the water the mixture displays the toroidal effect and Rayleigh-Taylor instability phenomenon. The droplets of dye will hold the shape of a 3 millimeter in diameter sphere until they strike the surface of the water. After they enter the water they begin to sink. This is to be expected because food coloring has slightly higher density than water. As the dye begins to fall through the water it begins to disperse. Initially the droplet will expand radially into a ring. This phenomenon is characterized as the toroidal effect in which the dye takes form of a

vortex ring. It occurs because the sides of the food coloring droplet get pushed upwards as it falls.¹ The figure below shows the toroidal effect:

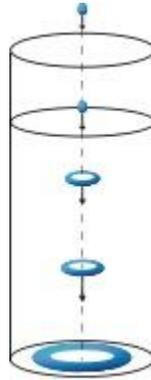


Figure 2: Toroidal Effect of a Falling Dye Droplet in Water¹

At a certain depth the dye droplet will become unstable and branch out into an umbrella shape. This phenomenon is known as the Rayleigh-Taylor instability. The three distinct stages of the dye droplet are determined and explained using its Reynolds number. As the Reynolds number increases, the dye droplet progresses from laminar flow to turbulent flow. As the droplet falls through the water up until it becomes unstable, it is laminar.² Once it becomes unstable and takes form of an umbrella, the dispersing particles are turbulent and chaotic. Once turbulent the dye rapidly disperses into tails that look similar to a mushroom shape. The Reynolds number is calculated:²

$$Re = \frac{U * R}{\nu}$$

where U is the velocity of the dye when the instability occurs, R is the initial droplet radius, and ν is the viscosity of the water assumed to be on same magnitude as the viscosity of dye.

U was estimated to be 0.05 m/s using a ruler and stopwatch (the dye became an umbrella at roughly a depth of 5 cm and it took roughly 1 second). The radius of a droplet is 1.5 mm. The viscosity of the water at 20 C is $1.0 \times 10^{-6} \text{ m}^2/\text{s}$.³

$$Re = \frac{.05 \frac{m}{s} * .0015m}{1.0 \times 10^{-6} \frac{m^2}{s}} = 75$$

This Reynolds number describes a fluid in laminar flow which may explain the umbrella effect; although, the dye is mixing into the water turbulently when it becomes unstable.

Visualization Technique

There are several factors that can make the image difficult to capture. First, determining the best time to take the image is a challenge. The dye will dilute into the water very quickly. The multiple colors will begin to blend and darken within a few seconds which will not yield a good photo. I chose to drop the blue dye in first and follow it with a drop of red dye about 2 seconds after. The photo must be taken within a few seconds of the last drop. It helps to have two people (one to drop the dye and the other to photograph) but can be done by one individual. Choosing colors is a fun part of the image. By experimenting with different color combinations a great image can be created. It is important to not use too much dye. Typically one drop of each color is plenty. Any more will cause rapid mixing and darken the whole glass of water. By offsetting each drop by a couple seconds, the mixing of colors can be minimized. The photo was taken with an all-white

background. This can be achieved by placing plain white paper underneath and behind the glass. A solid background will lead to the best picture. No flash is needed if the image is taken in a well lit room. Also deactivating the flash will remove any light reflection off the side of the glass. It is best to have a light source directly above the glass. The light source for this image was a chandelier consisting of five 60 watt tungsten light bulbs as well as natural light from surrounding windows. The camera should be roughly 6-12 inches from the glass. The layout can be seen in the figure below:

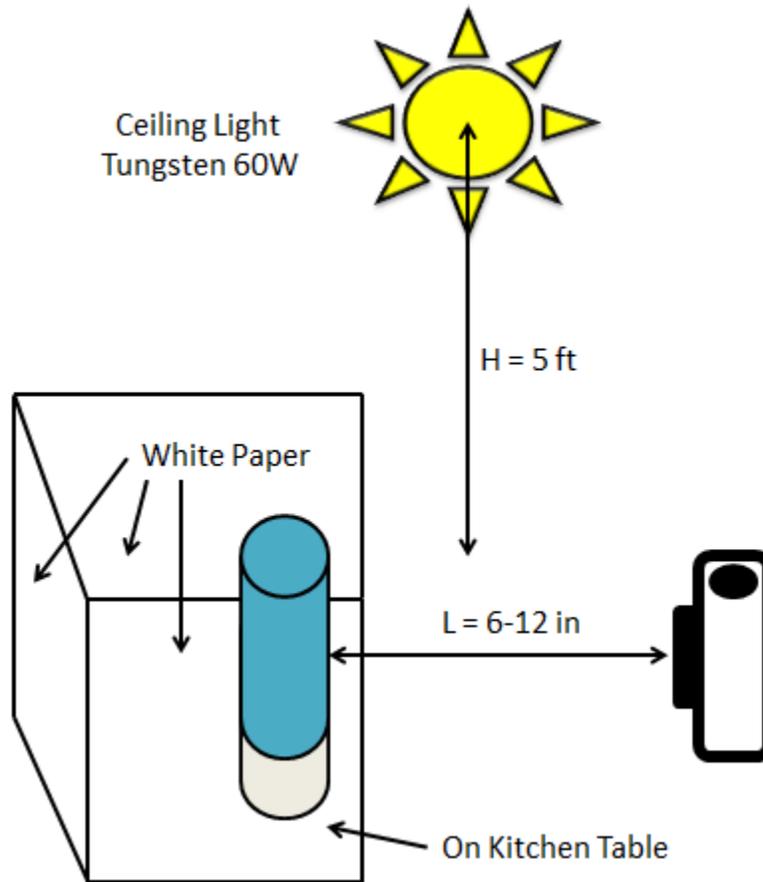


Figure 3: Photograph Layout

Photographic Technique

The images success is directly related to the photographic techniques used. The camera used was a point and shoot: Canon PowerShot SX230 HS (12.1 megapixels, 14x optical zoom, f3.1-5.9, 28-392mm (35mm equiv)).⁴ No flash was needed because the room was well lit and reflection off the glass was eliminated. The original photograph is 12 megapixels (4000 X 3000). The ISO was set at 640 to remove noise and ensure a clean image. The shutter speed was set to 1/30 of a second which allowed plenty of light and captured a clean focused image. Aperture was F3.1 which allowed a large volume of light to enter the lens. The combination of these settings allowed the exemption of a flash and captured the sharp detail and colors of the dye against a white background. To create the final image Photoshop was utilized. First, only a portion of the image was used. This was done by cropping that section. Since the picture was taken at an angle the perspective feature was used to stretch the bottom corners to create a rectangular image. Then the contrast and brightness were adjusted so that the dyes looked as if they were never in water but rather floating against a perfectly white background. Once the colors and sharpness of the image were satisfactory, the image was mirrored and

placed side by side itself. The spot healing tool was used to mesh the two halves together. A before and after of the image are shown in the Figure below.



Figure 4: Before (left) and After (right) of Image

Conclusion

Overall, the project was very effective. It involved learning and understanding camera settings and the power of Photoshop. Creativity drives taking photos of flow phenomenon. I tried many other scenarios. For example, I froze dye into ice cubes then dropped them into boiling water, I added thickening agents to both the water and the dye to change texture and viscosity, and I experimented with blending and shaking the mixture. Photographing these images can be very fun but requires patience and repetition. One thing I wish I experimented with is adjusting the temperature of the water. The dye behaves very differently depending on the water temperature. Although I think using Photoshop to artificially enhance this image was effective. I wish I would have kept it more natural. In the end, dye in water is a great way to create interesting flow visualizations, and no photograph will ever look the same. The image was overall successful.

References

- [1] Lewis, Ellen. "Toroidal Vortices « ." *Educational Innovations*. N.p., n.d. Web. 12 Feb. 2013. <<http://blog.teachersource.com/2010/01/07/toroidal-vortices/>>.
- [2] Youngs, David. "Turbulent Mixing Due to Rayleigh-Taylor Instability." *American Physical Society*. British Crown, 23 Nov 2008. Web. 12 Feb 2013. <www.aps.org>.
- [3] " Water - Dynamic and Kinematic Viscosity ." *Engineering Toolbox* . N.p., n.d. Web. 12 Feb. 2013. <http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html>.
- [4] " Canon PowerShot SX230 HS: Digital Photography Review." *Digital Photography Review*. N.p., n.d. Web. 12 Feb. 2013. <http://www.dpreview.com/products/canon/compacts/canon_sx230hs/specification>.