Get Wet

MCEN 4151: Flow Visualization

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For the initial assignment the goal was to capture the dynamic and turbulent flow of a hydraulic vortex and the cone such a flow generates. This initially began with trying to capture the shape of the cone formed by the vortex without using any visualization techniques. These photographs produced crisp pictures of the cone, but they did not convey the actual movement of the fluid. In order to better characterize the flow, dye was added in. This created a dramatic effect, as the dye would be either rapidly mixed in with the water in a turbulent fashion, or it would be swept down below the cone, where it would remain for extended periods of time without diffusing through the rest of the beaker. The objective of the assignment then became to capture this dual-natured flow, to show its elaborately complex movement near the edges of the beaker as well as the relatively calm and orderly flow found in the center of the vortex.

Figure 1: Vortex without dye

In order to fully realize this vision a small apparatus had to be constructed. This comprised of a 150 ml Pyrex beaker, tap water, red food dye, a 1 by .35 inch magnetic stirrer rod, and a magnetic mixer. The beaker would first be filled with approximately 140 ml of tap water and placed onto the magnetic mixer with the magnetic stir rod within the beaker. The magnetic mixer was then turned on and set to a power level of four on a one-to-ten scale of the mixer. This allowed for any bubbles trapped inside the water to be released from the beaker and make their way to the top. In some cases the beaker had to be wiped off to remove excess water droplets from the outside. Once the lighting and a neutral background were in

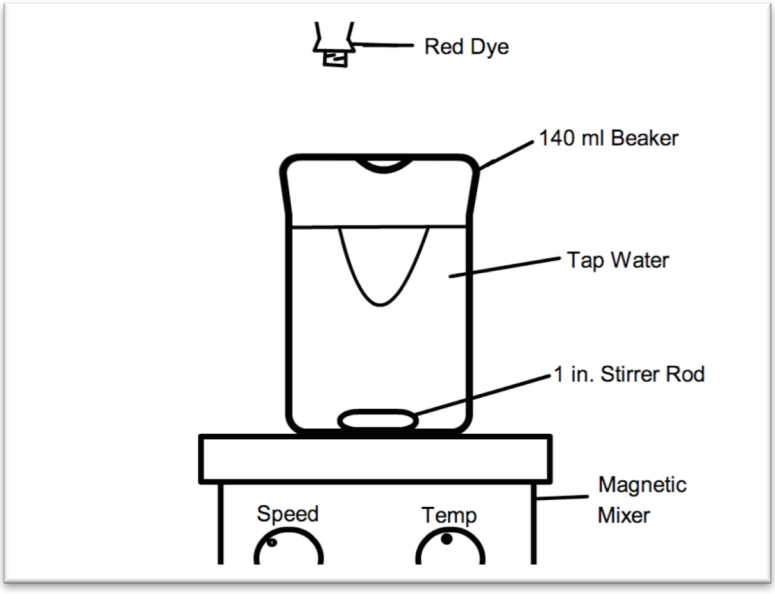

Figure 2: Schematic of fluid visualization apparatus

place the camera was set to the close up macro and placed approximately 6 inches away from the setup. At this point the initial two drops of yellow food dye were added. When the camera was properly zoomed and focused the red dye was released from approximately 2 inches above the surface of the water. The dye was introduced into the vortex in a variety of locations, from the outermost rim of the beaker to the very center of the vortex. To produce this image the dye was dropped half way between the center and the side of the vortex. Timing was paramount, as the dye would disperse very quickly throughout the water, but the images were captured by visual reflex, free of any timing apparatus.

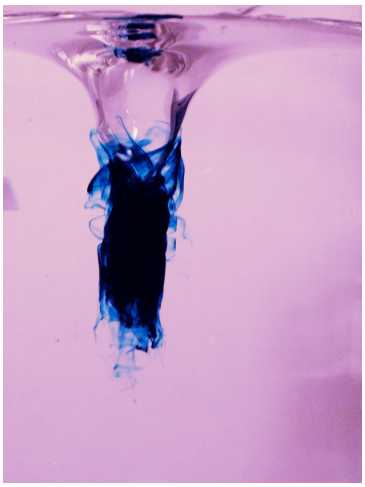

Figure 3: Blue dye dripped in the middle of the vortex

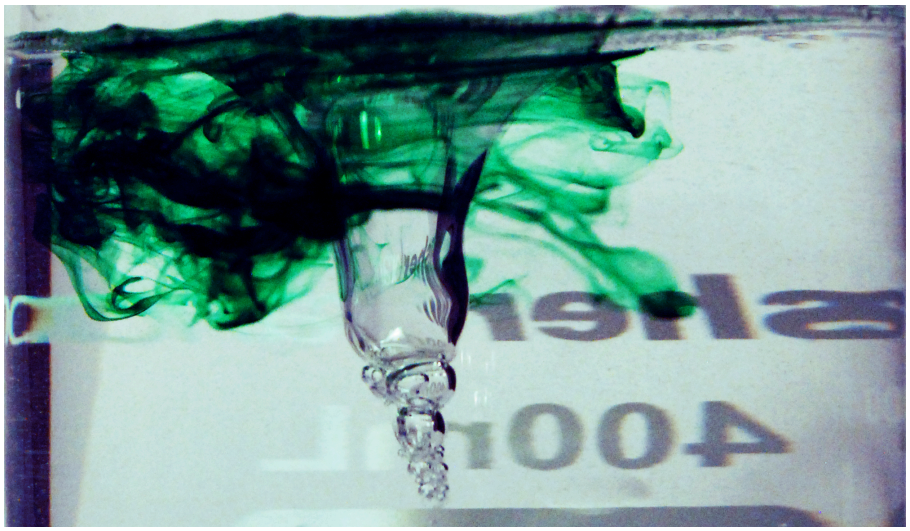

Figure 4: Green dye dripped at the side of the beaker

This process was repeated for over 700 photographs in order to get the right combination of the focus, lighting, framing, and timing. Multiple dyes were used, including red, blue, yellow, and green, as well as any combination of them. Each dye had different characteristics when it entered the water, but the red dye produced one of the most dramatic and clear images. This set up was also shot from a variety of angles from above and below the surface of the water, with and without the flash. The full range of speeds available on the magnetic stirrer were also investigated. The lower speeds did not produce the interesting cone shape, but higher speeds were too turbulent and were difficult to capture. Different magnetic stirrer rods were used as well, but the larger rods produced too

Figure 5: Turbulent flow from a larger, faster vortex

Figure 6: Wider vortex created by using a larger magnetic stirrer

much turbulence and a less appealing cone shape.

The final captured image relays many important features about the flow within the vortex. This particular vortex is a Burgers Vortex [1], as it has flow in both the tangential direction as well as an axial flow moving down the vortex. This inflow is what creates the unique cone shape at the surface of the water. The spinning magnetic stirrer pushes water at the bottom of the beaker to the sides and as a result water must be pulled down from above to fill the vacancy. This water is then systematically pushed away from the stirrer, up the sides of the beaker and back down through the center. All of this is occurring simultaneously with tangential velocity circulating the beaker.

Figure 7: Blue dye remains in the jet with minimal mixing into the red dye

These physics can be seen throughout the picture through several of the different features. First, there is the distinctive cone shape seen at the top of the waterline. The rapid spinning action of the vortex can be seen in the surface of the water as the red dye is pulled tangential to the motion of the vortex, but it is also being pulled downwards as can be seen in the striations. This action is also exemplified by the ring seen at the bottom of the dye as a very discrete trail of dye is dragged downwards in a circular motion. The direction of this flow can be seen to be primarily in the tangential direction.

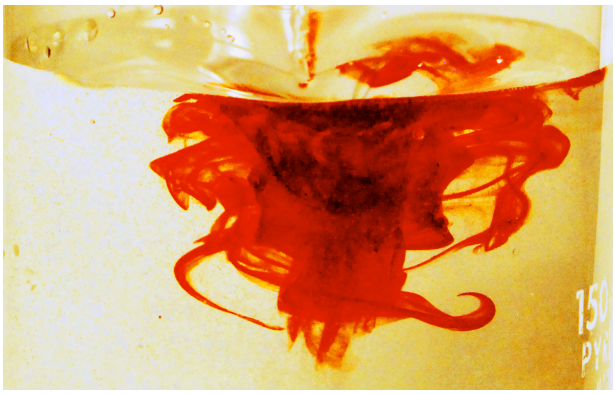

Figure 8: Red dye can be seen spiraling downwards around the jet in the turbulent region

The flow farther from the center of the vortex is much more turbulent, as it has not been caught in the downward jet of water found in the center of the flow. This dye is being acted upon by a mixture of forces, the general motion of the water traveling tangentially, the downwards pull from the jet, and the upwards motion of the water being accelerated by the magnetic stirrer.

Figure 9: Buoyant bubbles fight against anticentrifugal forces and the downward pulling jet

One of the more interesting features of this flow is the strand of bubbles that are trapped just below the vortex's cone. By looking closely it can be seen that this strand of bubbles actually continues downwards towards the center of the magnetic stirrer. At the center of the fluid there is a strong jet pulling downwards on the buoyant bubbles, holding them in place vertically but this does not explain their position horizontally. This is due to the presence of anticentrifugal forces at the center of the vortex [1]. Much like a denser object being pulled to the outside of a rotating system by centrifugal forces, less dense objects are pulled towards the center. As a result of these combined forces the bubbles remain in the center of the vortex, though they do move slightly in all three planes.

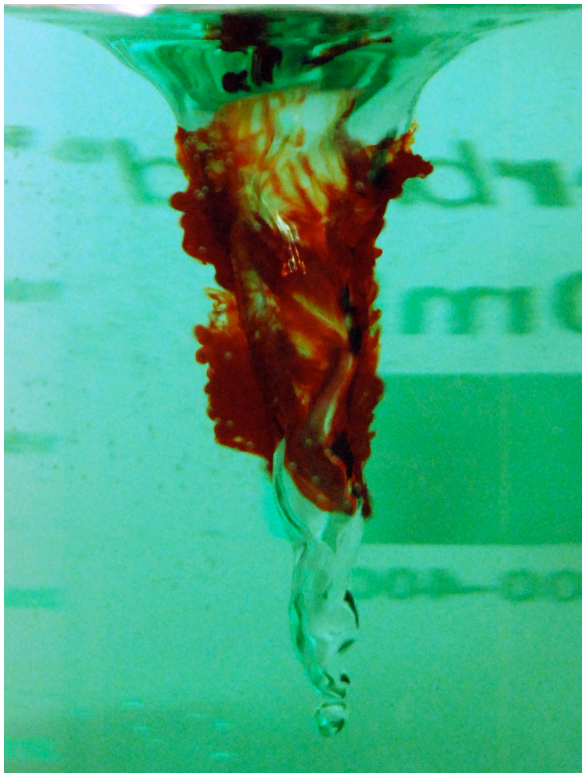

Figure 10: Red dye stays close to the cone as it gets pulled down and around

The arbitrary speed setting that produced the best looking flow produced a vortex that had a height of approximately 1.5 inches and a half-height width of approximately .5 inch. For this type of flow the viscous forces and gravitational forces are the most predominant [1]. To this end it would be beneficial to calculate the Reynolds number and the Froud number. The Reynolds number characterizes the importance of inertial forces with respect to viscous forces [2] while the Froude number relates the importance of inertial

forces to gravitational forces [3]. The approximate mean flow velocity of V = .25 $^{m}/_{s}$ (2 revolutions per second, ~3.8 cm diameter) can be coupled with other system parameters such as density (ρ= 998.23 kg⁄m^3), flow length (L=.0381m), dynamic viscosity (υ=1.002 N•s⁄m^2), rotational speed of the mixer (N=8rps), diameter of the mixer (d=.00635m), and gravity (g=9.81m⁄s^2) to calculate these crucial numbers:

$$Re = \frac{\rho V L}{\upsilon} = \frac{\left(998.23\ ^{kg}/_{mm^3}\right)\left(.25^{m}/_{s}\right)(.0381m)}{1.002\ ^{Ns}/_{m^2}} = 9.5$$

$$Fr = \frac{N^2 d}{g} = \frac{(8rps)^2(.00645m)}{9.81\ ^{m}/_{s}} = .414$$

It can be seen from these parameters that the viscosity of the fluid is not as important as the inertial forces and that gravity is more important than the velocity of the fluid.

Table 1: Camera Specifications

Camera	Nikon D80
Lens	Aspherical 28-80mm 1:3.5 - 5.6
Date	1/25/11 15:27
Shutter Speed	1/800 sec
F-Stop	f/7.1
Aperture Value	f/7.1
ISO Speed Rating	1600
Focal Length	80.0mm
Flash	Did not fire
Pixel Dimensions	2592 x 3872
Resolution	300 pixels/inch

To capture this flow a digital single-lens reflex camera was used. The final image was shot from 80.0 mm away from the center of the lens. This resulted was a field of view that spanned approximately 5 inches by 7 inches before being cropped. The general parameters for shooting can be found in the table to the left. The actual setup for shooting this phenomenon consisted of many different elements. First of all there was the visual apparatus, explained earlier, consisting of the beaker, the neutral background, magnetic mixer, stirrer bars, and dye. This was used to produce the flow and visualization of the vortex. Next there was a set of two, 250 Watt floodlights used to light the scene. A whiteboard was used to bounce the light back and provide more even lighting. General supplies were kept nearby for quicker turnover time between shooting. A rag was

Figure 11: Photoshop provides a powerful editing tool

kept on hand for spills and cleaning the beakers. Finally a laptop was kept nearby to inspect the pictures at full resolution.

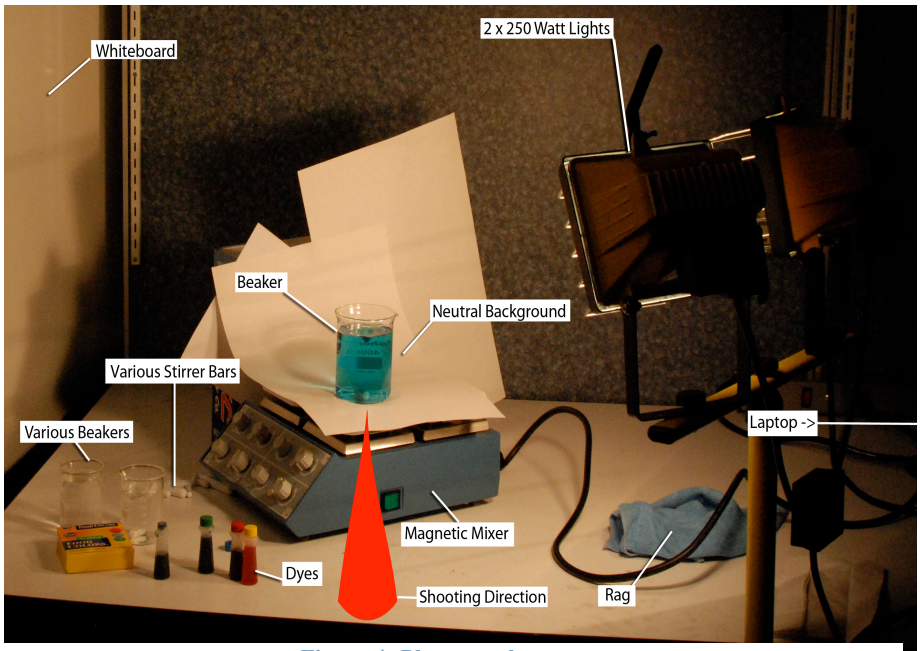

Figure 4: Photography setup

The laptop was also used for image editing. Photoshop was used heavily in this project to help to define the flow. It was initially used to crop and rotate the picture so that it could be better framed. Next, the image was sharpened with a filter to define the boundaries of the flow better. The picture was then adjusted for brightness and contrast, increasing both quantities slightly to result in a slightly crisper picture. Finally, the curves adjustment tool was used to adjust the individual levels of each color separately. The blue range was brought out significantly, resulting in the bluish background and also the darker regions in the red dye. Red and green levels were not adjusted nearly as much, only to bring out the areas of high concentration and cutting off areas of lower concentration. None of these operations adjusted the information within the picture, they simply adjusted the colors and contrast within the picture.


Figure 13: Original Photograph, one drop of red dye into one drop of yellow dye

While a certain level of Photoshop was necessary to make the colors really stand out, it would not have been possible to get the full range of colors from warm to cool without using the dye as a starting point. Food dye was purchased from a local grocery store and was a generic brand. Four colors were available and all had different tendencies in the water. Yellow was the least concentrated and

seemed to be one of the less dense dyes as it was diluted quickly in the vortex. It did, however, serve as a good base color to add to the beaker when 1-2 drops were added. Green and blue had very similar properties, they seemed to be more dense than the yellow dye, as they were easier to see diffusing slowly through the water. They may have been of a higher concentration, resulting in the higher density, and they resulted in nicely contrasting photographs. The red dye came in between all of these dyes, not dispersing as fast as yellow, but not as slowly as blue or green. When a single drop was added it produced vivid results that were not as dark as blue or as pale as white. Red did not provide much contrast against itself, making the flow look two dimensional, but Photoshop was able to add more definition.

Figure 14: Andy Warhol inspired image that was the initial inspiration for capturing this flow

Overall I would say that I thoroughly enjoyed this initial assignment. I believe that I was able to produce a picture that describes the nature of the vortex phenomenon, not to mention capturing a large number of secondary pictures. The main photograph catches the cone of the vortex drawing water down, exemplifies the turbulent region right outside of the downward jet, shows a very discrete trail of the dye moving down, and reveals the bubbles that are trapped within the jet. The only part of the flow it did not capture directly is the jet in the center of the vortex. This is only slightly revealed if one is to look closely at the flow right inside of the ring at the bottom of the dye, where the cylinder of

dye is beginning to form. With a little bit of background knowledge the full range of motion in this flow can be appreciated through this picture.

There are several aspects that I thoroughly enjoy in this picture, such as the very clear emergence of a ring at the bottom of the dye. I also like that you can see the swirling nature of the vortex from the surface of the water, but when it is viewed from below the surface it takes on a much more turbulent form. Then there are also the bubbles that are trapped in the center of the vortex. These show off some of the more complex and interesting flow dynamics while adding contrast to the picture. Finally there is the composition as a whole. I was aiming to have a full range of colors in the photograph, and through adjusting the curves I was able to achieve just that.

While there are many things that I enjoy about this picture there are a few small features that I could do without. First of all there is the label on the beaker. I had attempted to remove this with Photoshop but was unable to do so convincingly. Then there is also the slightly grainy nature of this picture, mostly likely due to the high ISO setting used. Finally I do not care for the distortion of the top of the vortex by the beaker. I feel as though some of the information of the flow has been distorted by the bending of the light by the glass.

Figure 15: The two images directly before and after the final photograph reveal satellite bubbles trapped by an unknown force. These bubbles are also in the final photograph.

If I were to restart this project from the beginning right now I would change very little about the process used. First of all, I would most likely use a tripod. This would allow for more consistent images as well as less motion blur. The tripod would be coupled with shooting the vortex from below the waterline, which I feel better captures the flow. Next, I would use glassware that was free of distracting labels. Other than that I would simply take more pictures. The camera that I was using was lent to me and it ran out of batteries eventually,

unfortunately it was right as we began getting some of the best results. As stated earlier, I am very happy with the final product of this project. I believe it is a dynamic photograph that captures the feel of a colorful lab experiment with a bit of mystery as to why there is a vortex in a beaker and what the pill on the bottom is for.

Figure 16: Get Wet final image submission

Works Cited

[1] Halasz, Gabor, Balazs Gyure, Imre M. Janosi, K. Gabor Szabo, and Tamas Tel. "Vortex Flow Generated by a Magnetic Stirrer." *American Journal of Physics* 75.12 (2007): 1092. Print.

[2] "Reynolds Number." *Wikipedia, the Free Encyclopedia*. Web. 11 Feb. 2011. <http://en.wikipedia.org/wiki/Reynolds_number>.

[3] "Froude Number." *Wikipedia, the Free Encyclopedia*. Web. 11 Feb. 2011. <http://en.wikipedia.org/wiki/Froude_number>.