Dye in a Vortex

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1 Purpose

This video was captured for the third team project in the class titled *Flow Visualization* at the University of Colorado. It was captured with the intent of visualizing an interesting flow phenomenon. The flow represented in this video shows dye droplets with a density greater than water intially suspended in a vortex as the centrifugal force pulls outward on it and keeps it from sinking towards the bottom of the glass.

2 Experimental Set-up

The experimental set-up used to capture this video included a standard 12 ounce glass filled a little over half way with water, multiple colors of dye, a simple white backdrop, a ceiling mounted fluorescent light fixture, a camera and a stirring rod. The process involved stirring the filled glass for 45-60 seconds; or until a noticeable vortex began forming, then removing the stirring rod and immediately dropping a dye droplet in the center of the vortex. Multiple dye colors and droplets were dropped in as time elapsed. Refer to the set-up in Figure 1.

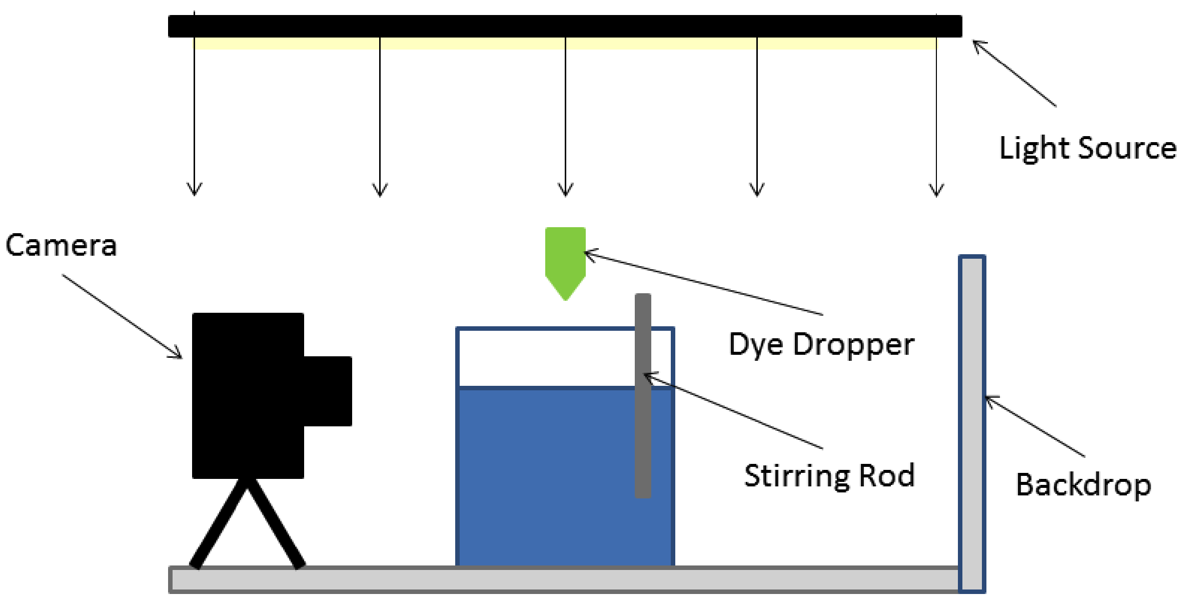

Figure 1: Experimental Flow Set-up

3 Flow Analysis and Calculations

The simplest description of this flow was hinted at in the introduction section. The centrifugal force of the vortex immediately acts on the dye droplet as it breaks the surface of the water. The force causes the dye to spiral outward as it is pulled into the wake of the vortex and instead of venturing down due to its greater density, it is suspended towards the surface of the water. You can see very well in this image the collection and disbursement of the dye into what are known as irrotational vortices [1]. This is what creates those sort of layers in the blue dye once the dye is initally dropped. Refer to Figure 2 for a representation of irrotational vortices.

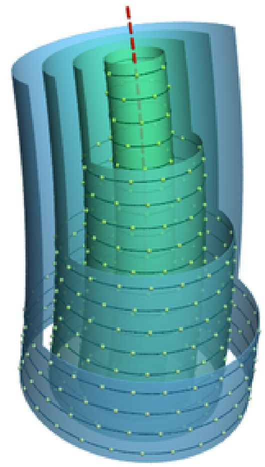

Figure 2: Example of Irrotational Vortices [2]

To fully understand the nature of the vortex, it is important to calculate the tangential velocity of the vortex based on its angular velocity. Using the velocity we can then begin to quantify and discuss the forces present in this situation and comment on the important dimensionless values to note the turbulent nature of the vortex. Taking in to account that the camera was recording at 30 frames per second and that the part of the vortex with a diameter of 1" made it around in ten frames. We can estimate the tangential velocity of the vortex:

$$V_r = \frac{2\pi r}{t} = \frac{2\pi(.013 \ \ m)}{(.34 \ \ s)} = .24 \ \ \frac{m}{s} \tag{1}$$

Using this velocity we can calculate the centrifugal acceleration that causes the dye to be suspended as it forms the irrotational vortices in Figure 2:

$$a_c = \frac{{V_r}^2}{r} = \frac{(.24 \ \ \frac{m}{s})^2}{.013 \ \ m} = 4.5 \ \ \frac{m}{s^2} \tag{2}$$

The magnitude of this acceleration in comparison to the scale of the vortex is huge. This is why the dye expands outward as rapidly as it does. The centrifugal acceleration forces the dye from the center of the vortex the second it hits the water. The rapid expansion in the x direction keeps the dye from traveling downward in the y direction. This is why at the end of the movie the red dye pierces through the blue only to go straight to the bottom. Since the vortex has slowed down, there is no centrifugal acceleration to keep the red dye suspended and thus its greater density pulls it straight to the bottom.

Now that we have commented on the suspension of the dye towards the surface of the water, we can comment on the Reynold's number of the vortex and help classify this as either laminar or turbulent flow [3].

$$Re = \frac{V_r D}{\nu} = \frac{(.24 \ \ \frac{m}{s})(.025 \ \ m)}{(.8x10^{-6} \ \ \frac{m^2}{s})} = 7.5x10^3 \tag{3}$$

Obtaining a relatively high Reynold's number tells us that vortices are classified as turbulent flow. This is mostly due to the fact that they experience such high tangential velocities while having a respectively small diameter. The smaller the diameter, the higher the Reynold's number and the more turbulent the vortex becomes. Vortices are an excellent visualization of turbulent flow as they follow no specific pattern and are very hard to predict.

4 Visualization Technique

The specific visualization technique used to capture this video was to ensure there was an appropriate vortex at the center of the glass and drop the dye directly into the center of this vortex. This ensured that the camera would be framing the phenomenon appropriately. As well as keeping the camera centered on the vortex, it was important to keep the top frame of the video just below the surface of the water. This eliminates any distractions of the glass and its surroundings.

The lighting wasn't complex. It was a fluorescent light fixture previously fixed to the ceiling approximately above the glass with the water in it. The light fixture was simply turned on to provide overhead light and illuminate the dye/water combination as much as possible without causing glare on the glass.

5 Photographic Technique

The field of view or frame of this video was approximately 2 inches from left edge to right edge. It was captured using my iPhone 5 with a distance from lens to glass of about 1 inch. Refer to Table 1 for specific exposure settings. The pixel count of the video is 1920 x 1080 and since the video was not cropped at all,

Table 1: Constants For Truss Problems

Setting	Value
Lens Focal Length	$2mm$
Aperture	3.2
Shutter Speed	$30fps$
ISO	800

the final pixel count of the video remained the same. The video was filmed at maximum resolution, so no more decades of resolution were necessary in this video. The only thing that would have enhanced this video would have been if the frame rate was higher than 30 fps. Something more like 60 fps would have made the phenomenon more fluid and less choppy. There was no post-processing done to enhance or crop the image. It came out just the way I wanted in the first place.

6 Conclusions

This image greatly reveals the traditional behavior of a vortex in water. Using the dye, you are able to see how the vortex is affecting the water and in turn the dye. I really like the focus of the video, it cuts out the glass very well so that the audience is focused on the actual phenomenon and nothing else. What I don't like as much is the graininess around the finer details of the dye. It is not a big deal, but I wish there wasn't as much noise. I did fulfill my intent fully and am very pleased with the end result. In the future, it would be cool to try to create vortices using other fluids and see how they react in comparison to this dye and water combination.

References

1. Ting, L. (1991). Viscous vortical flows. Lecture notes in physics. Springer-Verlag. ISBN 3-540-53713-9. Accessed May 1st, 2013

2. POV Ray. Website. Accessed May 1st, 2013
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3. engineeringtoolbox.com. Website. Accessed May 1st, 2013
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