MCEN 5151-002 Flow Visualization

Riley Curry, 10/05/24

Team First Project Report

The Making of "City Lights"

Figure I: "City Lights" Final Image

(I) Project Background

The image shown in Figure I above was taken specifically for the Team First project; part of the Flow Visualization curriculum at the University of Colorado Boulder. The goal of the project was to create a controlled flow scenario which actively and accurately demonstrates a flow phenomenon in a controlled setting with artistic aesthetic in mind. This image is the result of several experimented techniques until a desired aesthetic criterion was met; the goal was to take an image highlighting the refractive properties of different fluids by imaging the "shadow" of food dye dropped in a tank of water. Additionally, as can be seen in the image, the refraction of light on the disturbed water surface created unintended visual artefacts reminiscent of the Aurora Borealis phenomenon.

(II) Image Flow

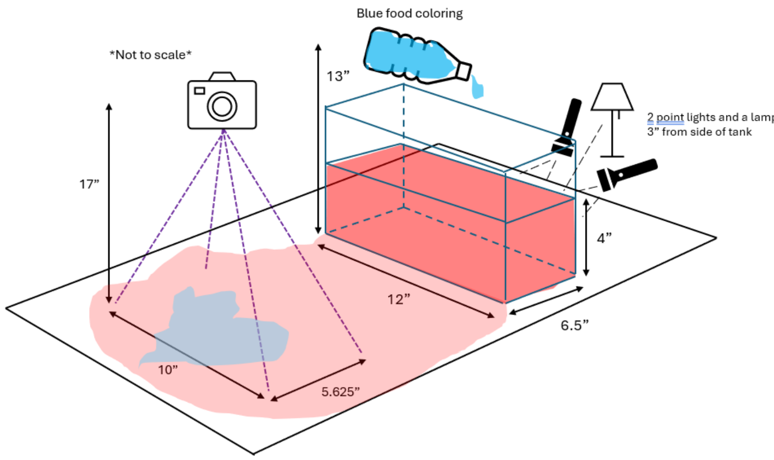


Figure II: Set-up Diagram

The image itself was captured in a darkened closet space reminiscent of the Figure II diagram shown above, with the camera providing a top-down view of the phenomenon. The 16:9 picture captures a physical area of 10" x 5.625" to capture as much information as possible without including distracting features such as the floor around the white posterboard on the ground. Approximately 3 drops of blue food coloring were dropped about 9" above a tank of settled dyed water (colored red with 5 drops of red food coloring) and an image was taken about 1 second after dropping. The image itself captures the refractive behaviors of light through the water via the soft edges around the blue food dye and yellow artefacts caused by a surface disturbance seen throughout the image.

(III) Flow Physics

As the three drops (~0.15mL) of blue food dye are dropped on static water, they retain ~0.00035 Joules of gravitational potential energy (https://archpdfs.lps.org/Chemicals/Food_coloring.pdf).

$$m = 1.025\frac{kg}{L} * 0.00015L = 0.00015kg \text{ ->}$$

$$U = mgh = 0.00015kg * 9.81\frac{m}{s^2} * 0.229m = 0.00035J$$

Though this is a comparatively small amount of energy, the dye hits the water at 2.146 m/s; enough to cause a mild disturbance on the surface.

$$U = K = \frac{1}{2}mv^2 \text{->} v = \sqrt{0.00035J * \frac{2}{0.00015kg}} = 2.146\frac{m}{s}$$

As the dye enters the water, it does so in a supercritical fashion in which inertial forces cause the rapid diffusion of the dye throughout the water. This can be proven by calculating the Froude number of the droplets, which gives an idea of how quickly the dye is diffusing and what has the largest impact on its movement (Sequeiros, 2012).

$$Fr = \frac{V}{\sqrt{gl}} = \frac{2.146m/s}{\sqrt{9.81\frac{m}{s^2} * 0.003m}} = 12.51$$

where "l" refers to the characteristic length of the droplet (3mm). As Fr>1, the flow is supercritical, and diffusion is comparatively rapid. The diffusion could have otherwise been slowed down to a subcritical flow with Fr<1, which can be achieved via dropping from a lower point for a lower velocity.

The diffusion itself can be classified using Fick's Law of Diffusion, where Γ represents the particle flux through a point at a designated point in time (Milligen et al., 2005). Fick's Law is defined as:

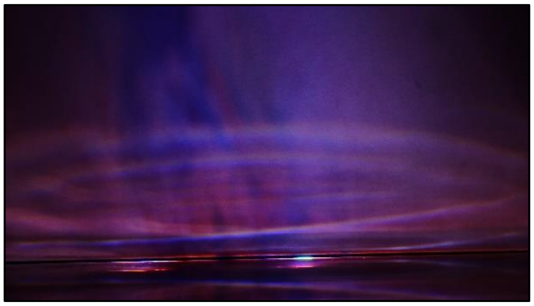
$$\Gamma(\mathrm{x,t}) = -\mathrm{D}\frac{\partial \mathrm{n(x,t)}}{\partial \mathrm{x}}$$

where "n" refers to particle density and D is the diffusion coefficient. This paper does not explore an analytical solution due to complexity and lack of data, however, the form of the equation provides a meaningful insight into the natural diffusion of the dye into the water, which is particularly reliant on its density. In other words, if the density of the dye were any higher or lower, I would be unlikely to get the same effect captured in the image.

(IV) Visualization Techniques

The experimental set-up follows the diagram shown in Figure II, taking place in a small dark room with no outside light allowed in. The tank itself is a 12"x6.5"x11.5" clear plastic file organizer from Michaels, which I filled with 5.11L (4") of tap water. The water itself was colored with 5 drops of red "Satin Ice" food color gel food dye which was mixed with a spoon and allowed to settle. Below the tank I placed plain white posterboard to increase reflection, and on the sides, I taped black posterboard to avoid distracting light reflection. On one side of the "tank" I placed a lamp 3" away, where I also hung 2 LED headlamps to provide better lighting. The lights were composed of 2 LED 400 lumen headlamps hanging off a 4.5W diffused lamp. Before dropping the dye, I prepared my camera settings and optical zoom and familiarized myself with its position so I could capture as much of the tank as possible. I did not have a large enough tripod and so I dropped the dye in with my left hand and took a photo with my right shortly after. I held the dye an inch above the tank (roughly 13" off the ground) dropped 3 droplets into the tank, and (with my camera roughly 17” off the ground) I took a singular image approximately 1 second after dropping. I performed this 4 times before capturing a satisfying result.

(V) Photographic Techniques



Unedited Image Edited Image

Figure III: Image Comparison

The image captures the majority of the length of the tank (which can be seen at the bottom of the image) with a captured area of 10” x 5.625” provided by the camera approximately 17” from the ground. The unedited image shown in Figure III above was taken on a Fujifilm XT30 II digital mirrorless camera with f/16 (for a balance between the low light conditions and image sharpness). The image was cropped and rotated such that the line of the tank at the bottom was horizontal. As such the unedited image size is 6240x3512 and the edited image size is 5921x3332. A shutter speed of 1/125 with an ISO of 1600 was used with an XC15-45mm interchangeable lens and 44.5mm focal length. This shutter speed was chosen for clarity and the ISO was chosen to counteract the low light conditions that came with the faster shutter speed and higher f-stop. A dynamic range of 100% was also used for exaggerated color as well as an incandescent white balance (built in setting) to counteract the sterile lighting. In post-processing, using Adobe Lightroom, the highlights and shadows were balanced for an overall brighter image with deepened color grading.

(VI) Conclusion

“City Lights” to me draws a comparison between the natural diffusion of dye in water and the diffusion of clouds in the sky, with added interest in the impact of surface displacement on light refraction off the surface of the water. The latter phenomenon was initially unexpected due to the outside light source being placed below water level, but it added an additional area of interest to consider when pondering the fluid physics of the image. That said, the image is not exactly what I had in mind, and I realize the phenomenon of refraction is not readily apparent given the image alone. Without a background into how the image was taken, the image is not easily understandable at first glance, and this is something I would like to improve on in the future. The final image is also a bit darker and less contrasted than I was aiming for, which I think could have been solved using a better lighting set-up. It is because of these factors that I ask myself how the image could be made more interesting, and how it could be made sharper. In future iterations of this experiment, I would like to test different fluids to attain a sharper refraction, as well as test different lighting set-ups to improve overall visibility.

Bibliography:

Sequeiros, O. E. (2012). Estimating turbidity current conditions from channel morphology: A Froude number approach. Journal of Geophysical Research: Oceans, 117(C4). https://doi.org/10.1029/2011JC007201

Milligen, B. P. V., Bons, P. D., Carreras, B. A., & Sánchez, R. (2005). On the applicability of Fick's law to diffusion in inhomogeneous systems. *European Journal of Physics*, *26*(5), 913–925. https://doi.org/10.1088/0143-0807/26/5/023