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MCEN 5151

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Team Second Report

Introduction:

For the second group project our team wanted to experiment with paint introduced into water. Our initial intent was to capture the turbulence that was occurring once the paint was introduced into the water. With the help of Luke McMullan, Joanna Bugajska, and Quyncie Grenis, we tried a multitude of different colors, viscosities, and heights when pouring the paint into the water. Our main motivation for this type of project came from Alberto Seveso. [1]

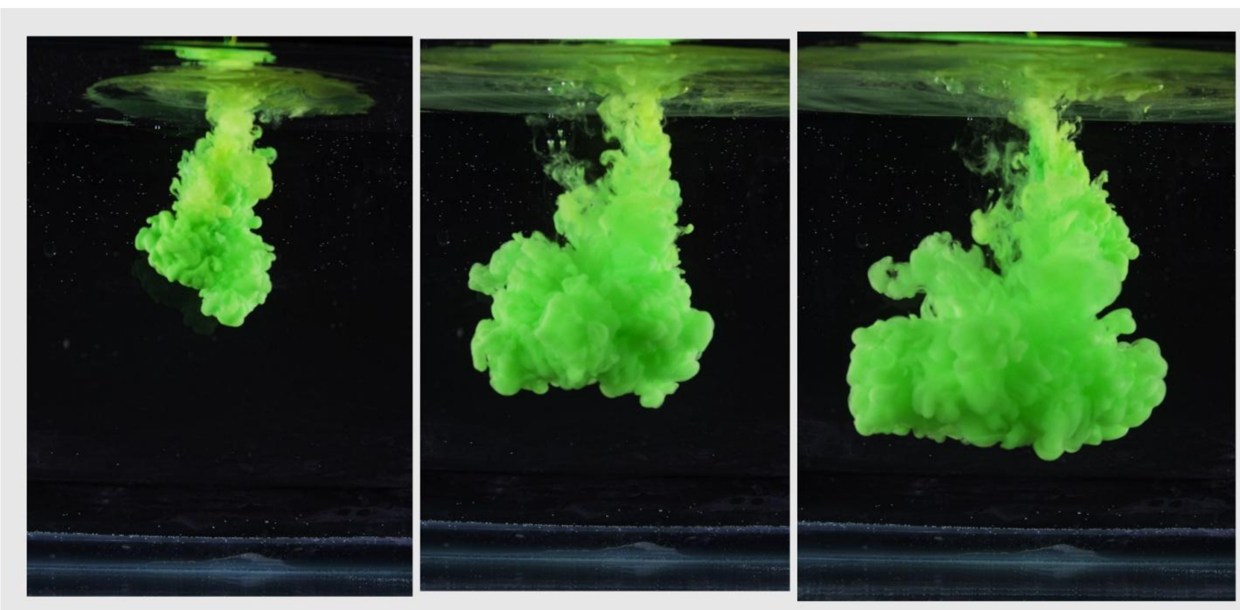


Figure 1: Green & Yellow Paint Dropping into Water

Physics:

There are a few interesting phenomena occurring in this interaction. The first and most obvious being the transition of laminar to turbulent flow. Laminar flow is defined as "flow of a fluid when each particle of fluid follows a smooth path in which those paths do not interfere with one another." [2] Turbulent flow is flow on which "the fluid undergoes irregular fluctuations, or mixing." "In turbulent flow the speed of the fluid at a [given] point is continuously undergoing changes in both magnitude and direction." [3] As the paint is dropped into water tank, the laminar flow of paint slowly being poured into water changes dramatically into a turbulent flow of visible proportions. Other than by inspection, flow can be categorized into these two areas by the Reynolds number. The Reynolds number is defined as Re = ρVL/ μ, where ρ is the density of the fluid, V is the characteristic velocity scale, L is the system length scale, and μ is the fluid viscosity. [4,5] However, Reynolds number is usually applied in either a flow in a pipe or over a flat plate, so the analysis does grow in complexity when applied to these constraints.

To determine an appropriate Reynolds number, one must look further into the fluid viscosities of both mediums. In basic terms, a fluids viscosity is the thickness of the fluid. It tells you how much force you would need to apply to move that fluid or keep it moving. [6] This can be mentally visualized by comparing honey and water. Honey is much more viscous liquid that requires more effort to move than normal tap water. [9] Paint is not a simple single-molecular that can easily be identified to determine viscosity. Rather, it is a complex conglomeration of chemical ingredients that can range from rather oil paint to water colors. Through experiment we found that if the paint was too viscous, the water wouldn't diffuse the paint and the result would be less that atheistically pleasing. We found by lowering the paint's viscosity by a slight dilution with water, we were able achieve the desired output.

At room temperature, μ for water is approximately $1\text{x}10^{-3}$ (Pa-s) and paint is approximately $1\text{x}10^{-1}$(Pa-s). Given these values, the following calculations for each were made.

Figure 2: Reynolds Number Approximation

$$\text{Re}_{\text{water}} = \frac{1000\left(\frac{kg}{m^3}\right)*1.5\left(\frac{m}{s}\right)*.05(m)}{1\text{x}10^{-3}(\text{Pa}*\text{s})} = 75000$$

$$\text{Re}_{\text{paint}} = \frac{1200\left(\frac{kg}{m^3}\right)*1.5\left(\frac{m}{s}\right)*.05(m)}{1\text{x}10^{-1}(\text{Pa}*\text{s})} = 9000$$

The combination of these two liquids presents further complication in attempting to find a Reynolds number to classify this particular flow. With further guidance I am confident one could prove this flow is turbulent in the given fluid medium of water. After much independent research it appears this classification is currently still under heavy research as the literature was sparse at best.

Another phenomena worth investigating is that of the “Rayleigh-Taylor instability.” This phenomena is when the “instability of a heavy fluid layer [is] supported by a light one.” [10] Another to look at it would be to say the lighter fluid (less dense) is pushing the heaver fluid (more dense). There is a lot of brilliant imagery of this phenomena whose aesthetics are striking and resemble the photos seen here. Unfortunately, for this particular experiment, the driving force was the more dense, more viscous fluid. The density of paint is approximately 1200 kg/m^3 whereas the density of water is approximately 1000 kg/m^3. I do not believe this phenomena should be further investigated as the situation seems to be the opposite of the Raleigh-Taylor instability.

An additional phenomena that merits exploration is that of turbulent plumes. These plumes, very similar to the plume of the paint in water, have a sharp boundary separating the turbulent buoyant fluid from the surroundings. I believe this could possibly be what is occurring here as this boundary layer is made in two steps. The first being the fluid engulfs in large eddies.[11] In these pictures, that would be the initial contact point of the water and the paint. The result is this beautiful imagery of the grandiose plumes emerging from a tiny stream of paint. The second step is a smaller scale of “mixing across the central core.”[11] This would more refined in the middle of plume which is obviously difficult to capture. If nothing else this further solidifies the earlier assertion of turbulent flow within the tank.

I believe the last main physical phenomena that is occurring here is that of surface tension. The paint we used before diluting had a high surface tension. This encouraged the liquid to bead once it hit the water rather than being spread out through the water. [7] We even saw this early on when the paint had not been diluted as we poured it into the water. By diluting the paint with water, the water acted as a surfactant by lowering the paint’s overall surface tension. I believe water worked as well as it did because the paint was water soluble. Had the paint not been water-soluble I don’t believe we would have achieved the result we were searching for. Other applications of surfactants can be seen in nature with semi-aquatic insects and in the energy industry with enhanced oil recovery. [7,8]

Procedure & Technique:

The following items were used to acquire the photographs

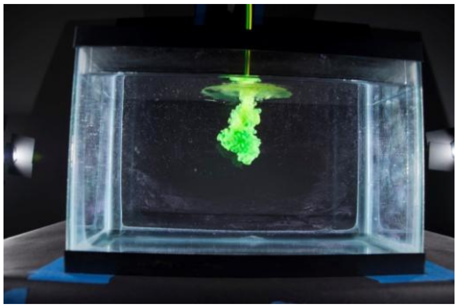
Table 1 - Items Used
Pro Art Liquid Tempera Poster Paint (Water Soluble)
Solo™ Cups (Clear/Plastic)
Approximately 1 Gallon of Water
1 Gallon Fish Tank
Black Paper/Poster for Back-drop
Tri-pod
250 Watt Lowel Pro-Light Focusing Floodlights (4) (Tungsten Balanced)
Water for Paint Dilution

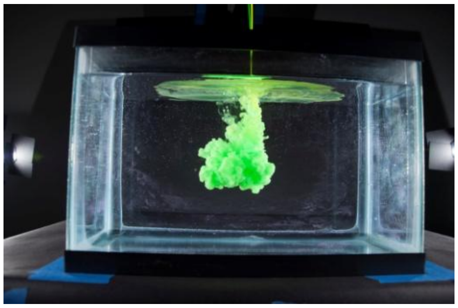
Figure 3: Setup

Similar to our previous experiment, by utilizing the lighting studio on the Colorado University campus, we were able to work in an open environment that let use control many of the variables. In the above picture you can see the setup we used for each trial. With the back-drop in place, we didn't have to worry about in unnecessary images appearing in the background. Additionally, the four lamps provided adequate lighting for our experiments. These 250 watt lamps were set at approximately 45 degrees from our setup. We felt this would illuminate the image the best. Our experiment began with filling the single-gallon tank with room temperature tap water. From there we chose a color of paint and proceeded to water it down to lower the viscosity of the paint. Through experiment we found if the paint was too viscous, we would not achieve the desired aesthetic we were striving for. With an approximate mixture of 4:1 (paint to water) we began pouring the paint as bursts of photos were taken. We experimented with several different color combinations once we were satisfied with the correct viscosity.

Camera Configuration & Processing:

The following were used for the camera Settings (Adapted from Joanna Bugajska)





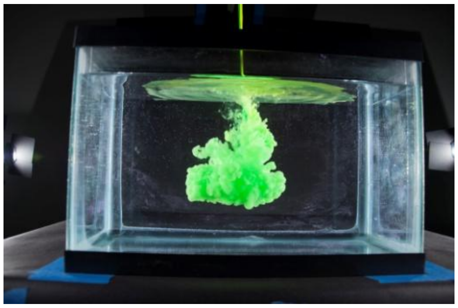


Figure 2-4: Original - 4288 x 2848 pixels

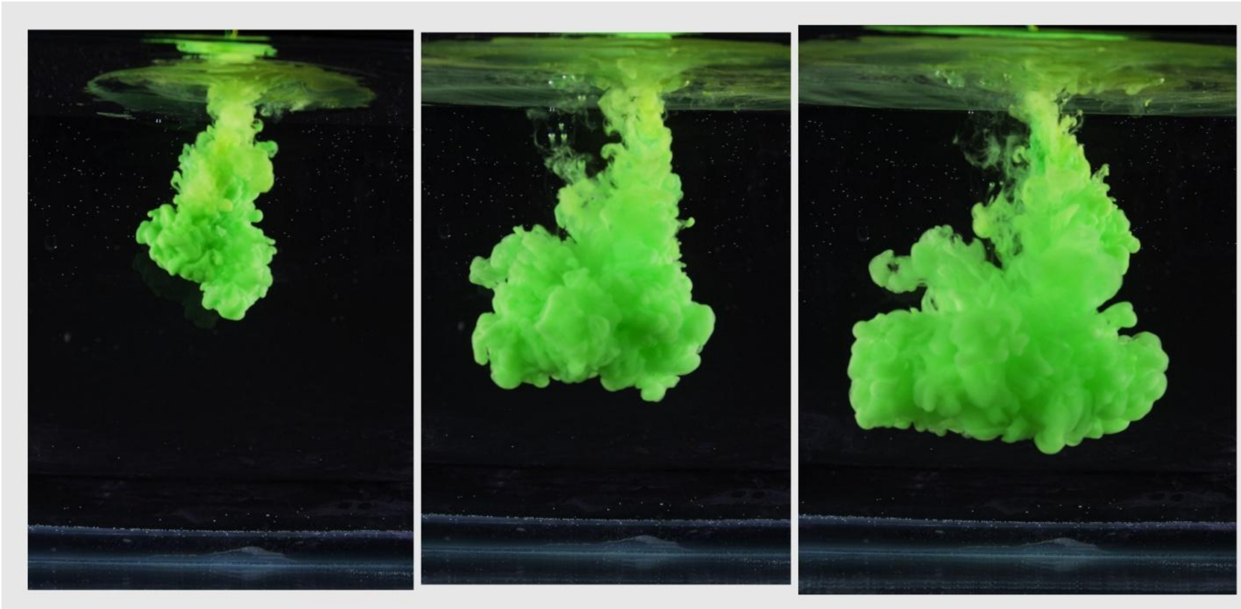


Figure 5: Final - 3712 x 1828 pixels

The following were used for the camera Settings (Adapted from Joanna Bugajska)

<u>Table 2 & 3: Camera Settings</u>

Camera Information	
Make:	NIKON CORPORATION
Model:	NIKON D90; S/N: 3448413
Owner:	
Lens:	18.0–105.0 mm f/3.5–5.6
Shot Information	
Focal Length:	18.00 mm (in 35mm: 27 mm)
Exposure:	1/1000 sec; f/3.5; ISO 400; Manual; Spot metering
Image Size:	4288 x 2848
Orientation:	
Resolution:	300.00 Pixel per Inch
Flash:	Did not fire

Camera: Nikon D90 DSLR camera 12 MP

Lens: Nikkor 18-105mm 1:3.5-5.6

Aperture: 3.5 f-stop

Shutter speed: 1/1000

Focus was set manually

BURST MODE: 4 fps

Utilizing the burst mode on the Nikon, we were able to capture several images as the paint fell and spread into the water. At a rate of four frames per second, one could estimate that for four sequential photos each is taken at .25 seconds increments. There is exactly one photo between each of the chosen above photos, putting the time between each of the chosen photographs at .25 seconds. Overall, the three above photos happened in approximately 1.5 seconds.

There was a moderate amount of post-processing done using the program GIMP (GNU Image Manipulation Program). Leveraging the GIMP software for my benefit proved to be more difficult than I initially thought. To achieve the desired “Time-Lapse” effect meant cropping and setting each of the individual photos within a new GIMP window. Getting them precisely where I wanted proved to be challenging as that is why there is a white border around each of photos. I then manipulated the colors with the “Curves” feature as well as the Brightness/Contrast features. Utilizing both of these tools darkened the background and brought out the fluorescent color of the green paint.

Analysis & Opportunities for Improvements:

I believe our process for our experiment was well thought-out. Slight improvements in exact measurements of the paint to water ratio could improve the reproducible nature desired for these photographs. However, after only a few minutes one could figure out a sufficient consistency for the mixture. Similar to our previous experiment, we also strived for consistent height to drop the paint, but this could be controlled better with an apparatus that dropped the paint at a reproducible height. This could obliviously then affect the velocity and turbulent nature within the flow. Additionally, with trying several different cameras, it did seem that we were limited by the technology at our disposal. The Go-Pro’s limited aperture and focus length did produce some rather washed-out and grainy images. Changing to the Nikon camera improved the overall quality of our images as these were the ones that were used by most in the group.

Although our images didn’t turn out as clean and crisp as Mr. Seveso’s, I was very pleased with our process and overall product. For amateur photography I believe we got as close as we could with the technology and time constraints. Personally I would probably not do three photos if I were to reproduce this image as post-processing was the most difficult. Adobe Photoshop may be more user friendly, but combining these three images in GIMP was anything but intuitive.

Additionally, I was also surprised at the lack of literature on physics behind this phenomena. Although there were several different artists performing this experiment that resulted in some breath-taking images, the science behind the phenomena seems lacking in comparison to previous projects.

Sources Used:

[1] "Sony Xperia Z & Tablet Z – O2 Guru TV." *Alberto Seveso*. Web. 17 Nov. 2015. http://www.burdu976.com/phs/portfolio/sony-xperia-z-tablet-z-o2-guru-tv/.

[2] "What Is the Difference between Laminar and Turbulent Flow?" *What Is the Difference between Laminar and Turbulent Flow?* Web. 17 Nov. 2015. http://www.physlink.com/Education/AskExperts/ae464.cfm.

[3] "Turbulent Flow | Physics." *Encyclopedia Britannica Online*. Encyclopedia Britannica. Web. 17 Nov. 2015. http://www.britannica.com/science/turbulent-flow.

[4] "Basics of Turbulent Flow." MIT. Web. 17 Nov. 2015. http://www.mit.edu/course/1/1.061/www/dream/SEVEN/SEVENTHEORY.PDF.

[5] Darling, David. "Reynolds Number." *Reynolds Number*. Web. 17 Nov. 2015. http://www.daviddarling.info/encyclopedia/R/Reynolds_number.html.

[6] "The Nerdly Painter." *Viscosity, Why Does It Matter?* Web. 17 Nov. 2015. http://nerdlypainter.blogspot.com/2011/01/viscosity-why-does-it-matter.html.

[7] "Lesson: Surface Tension Basics." *Surface Tension Basics*. Web. 17 Nov. 2015. https://www.teachengineering.org/view_lesson.php?url=collection/duk_/lessons/duk_surfacetensionunit_lessons/duk_surfacetensionunit_less1.xml.

[8] Sandersen, Sara B. "Enhanced Oil Recovery with Surfactant Flooding." (2012): iii-iv. Technical University of Denmark. Web. 20 Sept. 2015. < http://www.cere.dtu.dk/-/media/Centre/CERE/Publications/PhD%20Thesis/2012/Sara%20Sandersen%20phd.ashx?la=da>.

[9] White, Frank M. "Chapter 1." *Fluid Mechanics*. 7th ed. New York: McGraw-Hill, 2010. Print.

[10] Kull, H.j. "Theory of the Rayleigh-Taylor Instability." *Physics Reports*: 197-325. Print. http://www.ann.jussieu.fr/~frey/papers/instabilities/Kull%20H.J.,%20Theory%20of%20the%20Rayleigh-Taylor%20instability.pdf.

[11] Turner, John Stewart. "6.1.1 Axisymmetric Turbulent Plumes." *Buoyancy Effects in Fluids,*. Cambridge [England: U, 1973. Print.