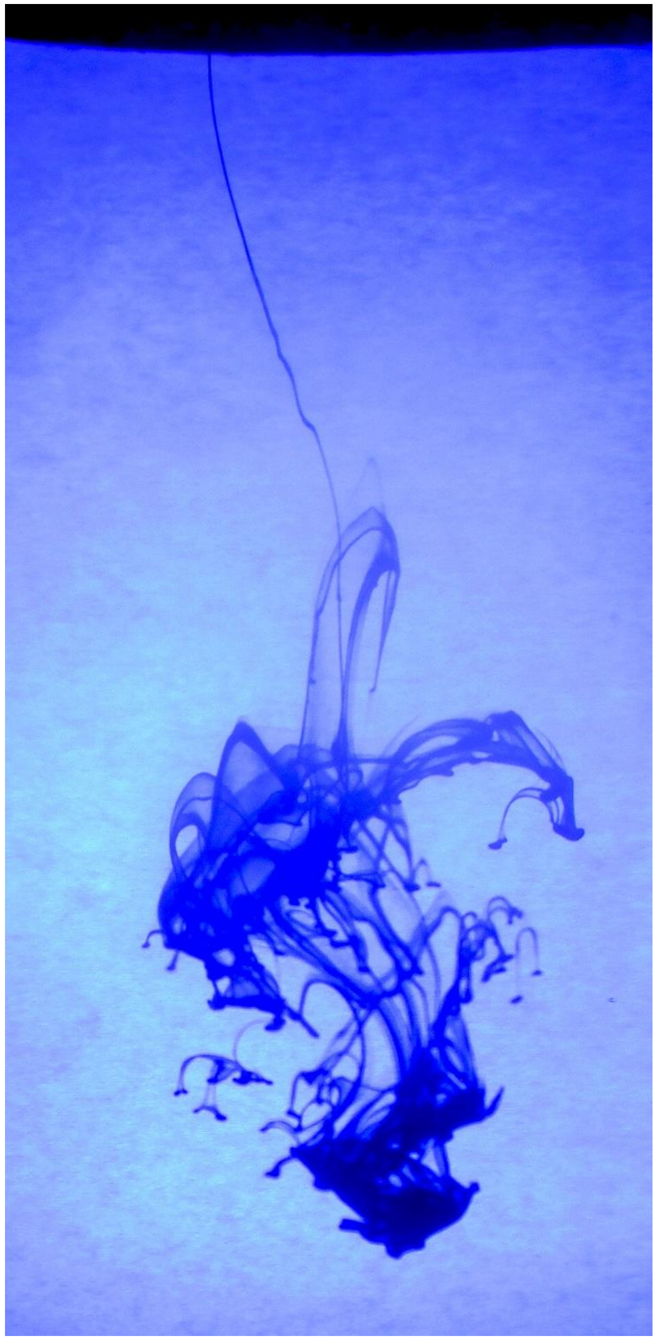
Project #1 – Get Wet



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MCEN 4151
Professor Hertzberg
2/16/2012

Purpose

The purpose for this visualization was for the "Get Wet" assignment assigned in the Flow Visualization course given at the University of Colorado – Boulder, led by Professor Hertzberg. The goal of the "Get Wet" assignment was to display the physics of fluid flow in both an experimental and artistic way. It was my intent to display the physics of surface tension and the Rayleigh-Taylor Instability in a focused and appealing way.

Materials

For this representation, I chose to use several materials that can be easily found at a local hardware store. This was done to allow the reader an easier way of replicating my results for future endeavors. The materials are as follows:

- 56 fluid ounce clear flower vase (8" Height x 4" Diameter) – Purchased at McGuckin's Hardware, Boulder, CO
- Daler Rowney FW Black India Ink – Purchased at McGuckin's Hardware, Boulder, CO
- Good Earth Lighting Black Light (120 VAC, 60 Hz, 15W, 1.5 feet in length) – Purchased at McGuckin's Hardware, Boulder, CO
- White Printer Paper
- Fujifilm Finepix J20 Point & Shoot Digital Camera

Procedure

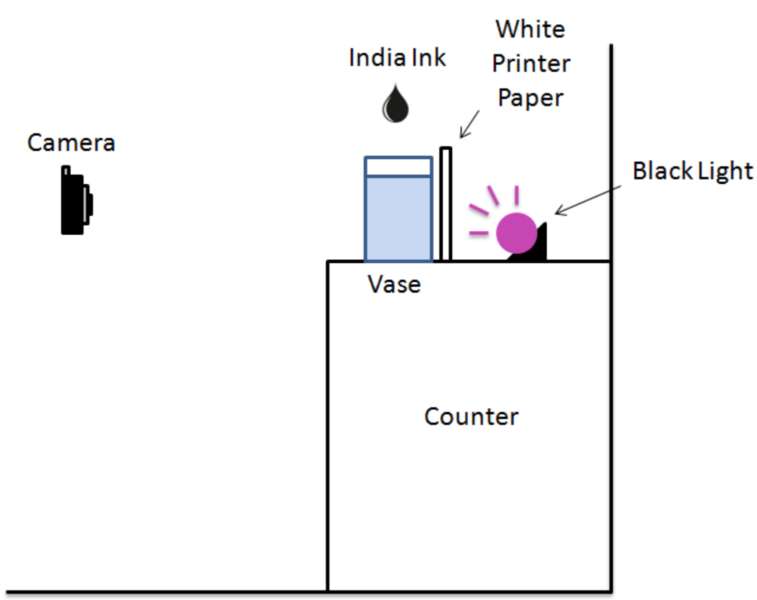


Figure 1: Experiment Setup

The full experiment setup can be seen in Figure 1 above. To setup this experiment, I filled the flower vase with 50 oz of water (40^{o} F), and placed it on a countertop in my bathroom. I then wrapped and taped white printer paper around the back half of the vase to supply a white background. The black light was placed 2 inches behind the vase, pointing at a 45^{o} angle on the same countertop. To initiate the experiment, I closed the bathroom door, eliminating all light from the room. I then turned on the black light, which in turn illuminated the printer paper, supplying for a fluorescent blue-purple background. I positioned myself 1.5 feet away from the vase with my camera, ready to capture the image in burst mode. I grabbed the India Ink, obtained as much ink in the dropper supplied, and slowly and carefully emptied the contents onto the surface of the water (10 full drops). The ink remained on the surface of the water for about 15 seconds, with a small stream eventually moving downwards in the vase. The stream traveled 3 inches, and then became turbulent and produced the Rayleigh-Taylor Instability shown in the image.

Fluid Dynamics

The two physics themes displayed in this image are surface tension and the Rayleigh-Taylor Instability. Due to the temperature of the water, the India Ink initially remained on the surface of the water, signifying the surface tension between the ink layer and the water surface. As the ink sat on the water surface, it began to accumulate towards the center of the vase, and eventually gathered enough fluid to form a thin stream that travelled downward in laminar fashion. The stream shows laminar flow on the first 2 inches of its progression downwards, then begins to show a transitional phase for 1 inch beyond that. The ink then enters turbulent flow at 3 inches of downward progression, all displaying the Rayleigh-Taylor Instability, and producing an appealing jellyfish-like effect. The Rayleigh-Taylor Instability is an instability of an interface between two fluids of different densities, which occurs when the lighter fluid is pushing the heavier fluid.[1] As the instability progresses, “dimples” are created and form several Rayleigh-Taylor fingers. The instability shown in the image measures roughly 3 inches in height and 2 inches in width. The reason the ink stream experiences three modes of stability (laminar flow, transitional flow, turbulent flow) can be explained with Reynolds Number. The equation for Reynolds Number can be seen below[2,3]:

$$Re = \frac{\rho V L}{\mu} = \frac{U_i R}{\nu}$$

where ρ = density, V = velocity, L = length of fluid, μ = viscosity, U_i = velocity of ink, R = radius of ink blob, and ν = kinematic viscosity.

To calculate U_i, the following formula was used[3]:

$$U_i = \frac{(\rho_i - \rho_w)R^2 g}{\rho_i \nu}$$

where ρ_i = density of ink, ρ_w = density of water, and g = gravity.

When calculating U_i[4], we will use $\rho_i = 1038\ kg/m^3$, $\rho_w = 1000\ kg/m^3$, R = 0.001875 m, g = 9.8 m/s^2, and ν = 4.7E-5 m^2/s (using conversion from centipoise to m^2/s). When applying these values to the equation, we receive the following value for U_i:

$$U_i = 0.026836\ m/s$$

When we apply the calculated velocity of the ink to the Reynolds Number formula, we receive the following value for Re:

$$Re = 1.07$$

The low Reynolds Number correlates to the viscous forces and inertial forces taking place in the liquid and indicates that they are nearly equal. If the Reynolds Number falls within the range of $1 \leq Re \leq 1000$, then an umbrella instability is to be expected from the droplet of ink. When Reynolds number falls into this range, the suspension drop deforms into a torus that eventually becomes unstable and breaks up into a number of secondary blobs[4].

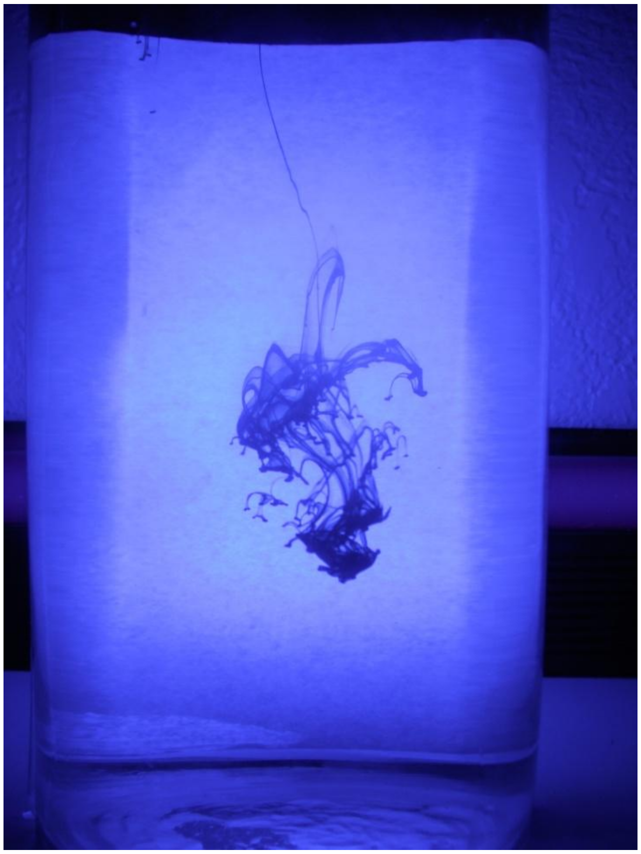
Photo Technique

For this experiment, I chose to use my Fujifilm Finepix J20 Point & Shoot Digital Camera. The field of view for the original photograph was 10 inches in height by 6 inches in width, and for the finished photograph was 6 inches in height by 3 inches in width. The distance from the outer edge of the vase to the camera was 1.5 feet. The dimensions for the original photo are 2736 pixels in width by 3648 pixels in height, and for the finished photo are 1248 pixels in width by 2568 pixels in height. The horizontal and vertical resolution was 72 dpi. The f-stop was f/3.1, with an exposure time of 1/56 of a second, ISO of 100, a focal length of 6 mm, and a max aperture of 3.27. I used the Gimp 2 software to perform editing on the image. Since I am fairly new image editing, I chose to keep it simple by cropping the image and adjusting the curves. Cropping the image allowed for the focus to be solely on the fluid flow, and I adjusted the curves so that the darker sections of the flow were lightened to provide more detailed visualizations of the flow occurring that couldn't necessarily be seen in the original image. I left the editing at those two aspects as I was content with what I had produced.

Conclusion

It was my objective of the "Get Wet" assignment to display two physics themes in an artistic yet very scientific way. I believe I effectively show the concepts of surface tension, the Rayleigh-Taylor Instability, and its personality with Reynolds Number. I believe that by using the black light as my light source, it creates an image appealing to the eye, creating interest and intent to know more on the reader's part. In the future, I would like to perform this experiment once again using a DSLR camera with increased shutter speed to improve the clarity of the end product. I would also like to take a digital video of the phenomena, and display surface tension and the Rayleigh-Taylor Instability in both real-time and slow motion.

Original Image



References

1. “Rayleigh-Taylor Instability”. *Wikipedia: The Free Encyclopedia*. http://en.wikipedia.org/wiki/Rayleigh%E2%80%93Taylor_instability. Accessed on February 15, 2012.
2. “Reynolds Number”. *Wikipedia: The Free Encyclopedia.* http://en.wikipedia.org/wiki/Reynolds_number. Accessed on February 15, 2012.
3. “Numerical simulation of finite Reynolds number suspension drops settling under gravity.” Bosse, Thorsten. Kleiser, Leonhard. Hartel, Carlos. Meiburg, Eckart. *Institute of Fluid Dynamics & the Department of Mechanical and Environmental Engineering of University of California at Santa Barbara.* http://me.ucsb.edu/~meiburg/pubs/Bosse_et_al_2005.pdf. Accessed on May 6, 2012.
4. “Dow Propylene Glycol USP/EP Technical Data Sheet.” *DOW*. http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_0048/0901b80380048696.pdf?filepath=propyleneglycol/pdfs/noreg/117-01619.pdf&fromPage=GetDoc. Accessed on May 6, 2012.

Image Assessment Form

Flow Visualization

Spring 2010

Name(s): Ryan Kelly

Assignment: Get Wet

Date: 12/16/2012

Scale: +, ! = excellent √ = meets expectations; good. ~ = Ok, could be better. X = needs work. NA = not applicable

Art	Your assessment	Comments
Intent was realized	!	
Effective	!	
Impact	!	
Interesting	!	
Beautiful	!	
Dramatic	√	
Feel/texture	√	
No distracting elements	√	Partial graininess could be distracting
Framing/cropping enhances image	!	

Flow	Your assessment	Comments
Clearly illustrates phenomena	!	
Flow is understandable	!	
Physics revealed	!	
Details visible	√	Could have used better camera
Flow is reproducible	!	
Flow is controlled	!	
Creative flow or technique	!	
Publishable quality	√	Clarity could be an issue

Photographic technique	Your assessment	Comments
Exposure: highlights detailed	!	
Exposure: shadows detailed	!	
Full contrast range	!	
Focus	!	
Depth of field	!	
Time resolved	√	
Spatially resolved	!	
Clean, no spots	!	

Report		Your assessment	Comments

Describes intent	Artistic	!	
	Scientific	!	
Describes fluid phenomena		!	
Estimates appropriate scales	Reynolds number etc.	!	
Calculation of time resolution etc.	How far did flow move during exposure?	!	
References:	Web level	!	
	Refereed journal level	!	
Clearly written		!	
Information is organized		!	
Good spelling and grammar		!	
Professional language (publishable)		√	
Provides information needed for reproducing flow	Fluid data, flow rates	!	
	geometry	!	
	timing	√	
Provides information needed for reproducing vis technique	Method	!	
	dilution	!	
	injection speed	!	
	settings	!	
lighting type	(strobe/tungsten, watts, number)	!	
	light position, distance	!	
Provides information for reproducing image	Camera type and model	!	
	Camera-subject distance	!	
	Field of view	!	
	Focal length	!	
	aperture	!	
	shutter speed	!	
	film type and speed or ISO setting	!	
	# pixels (width X ht)	!	
	Photoshop techniques	!	
	Print details		
	"before" Photoshop image	!	