Get Wet | MCEN 4151 Flow Visualization

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September 28, 2015

Introduction

The purpose of Get Wet is to demonstrate and capture a fluid (liquid or gas) or a combination of fluids with the goal of analyzing and understanding the underlying physics of the flow. A controlled experiment is carried out so that results are repeatable while simultaneously having the ability to capture an image or video. In planning the flow visualized in this experiment, the flow phenomenon desired was turbulent mixing of two liquids of different density or the Rayleigh-Taylor Instability. The techniques for visualizing the flow as well as techniques for photographing the flow are discussed below.

Apparatus Setup

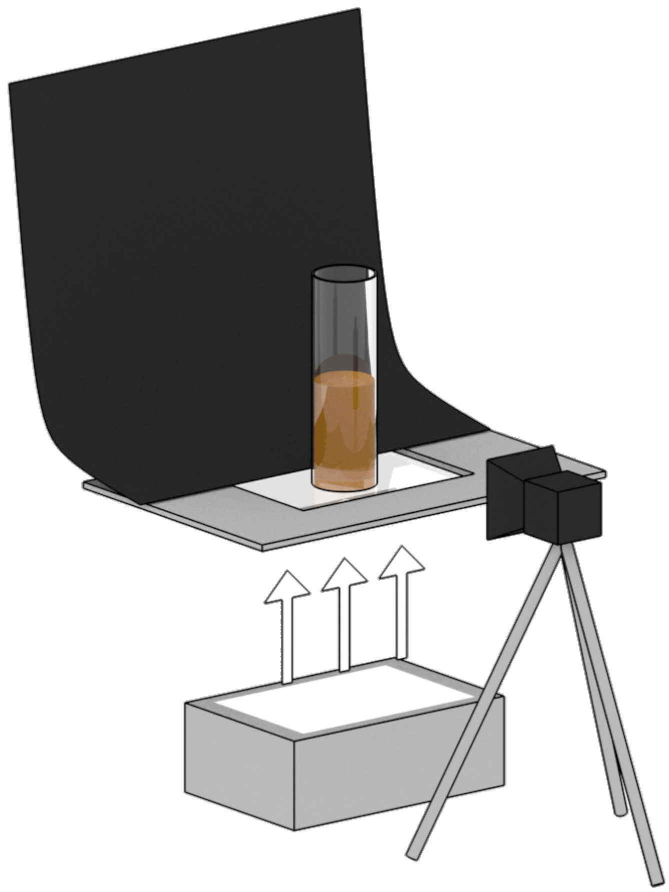

Figure 1: Apparatus setup showing the backdrop, light source, camera, and subject.

As shown in Figure 1, the apparatus can be set up by first using a table with a glass window as a platform for the fluid experiment. A cylindrical glass vase is used to hold the liquid and is placed on top of the glass window. For the light source, a construction lamp or any fluorescent light source is placed below the glass window so that light only comes from one direction. Furthermore, the apparatus should be placed in a pitch-black environment. A black backdrop is placed to prevent the light source from reaching unwanted backgrounds objects such as a wall. To provide a scale of the apparatus, the cylindrical vase shown has a diameter of 4.5 inches and a height of 30 inches, and the distance from the camera lens and the object is approximately 24 inches.

Fluid Dynamics

Reynolds Number

The Reynolds Number is a non-dimensional number that provides information of whether a flow is laminar or turbulent. If the apparatus is modeled as pipe flow, a Re number greater than 4000 would be considered turbulent flow, and a Re number less than 4000 is laminar flow.

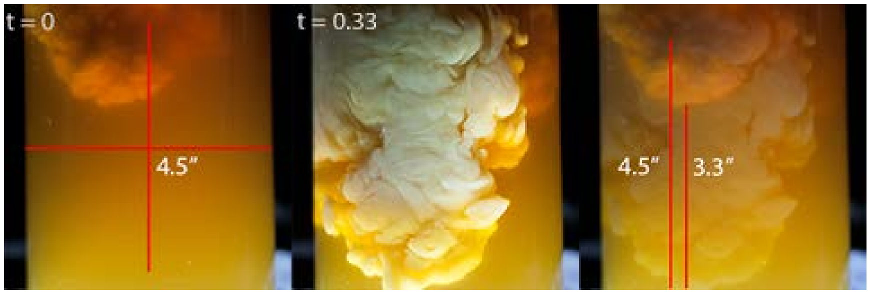

Figure 2: Two continuous shots shown with appropriate scale and both overlapped shots on the far right.

From Figure 2, two shots were taken continuously using the continuous shooting mode. The camera used can approximately shoot 3 frames/second at a shutter speed of 1/80 seconds. Given these numbers, it takes approximately 0.333 seconds for the second image to be captured. In the overlapped image on the far right of Figure 2, the flow approximately covers a distance of 3.3 inches in 0.333 seconds. Therefore, the velocity of the flow is approximately:

$$v = \frac{d}{t} = \frac{3.3\ inches}{0.333\ sec} = 9.9\frac{in}{s} = 0.251\frac{m}{s}$$

Provided that v = 0.251 m/s, [1] ρ = 1012 kg/m^3, [2] μ = 0.0071 kg/(ms), and L = 15 inches or 0.381 m where ρ is the density of light creamer, and μ is the dynamic viscosity of cream.

$$Re_D = \frac{\rho v L}{\mu} = \frac{1012\frac{kg}{m^3} * 0.167\frac{m}{s} * 0.381m}{0.0071\frac{kg}{ms}} = 13630$$

A Reynolds number of 13630 is greater than 4000 and suggests that turbulent flow is occurring in the vase.

Rayleigh-Taylor Instability

The flow phenomenon to be captured is the Rayleigh-Taylor Instability. When two fluids of different densities share an interface, two forces play a role in the stability of the flow [3]. To observe the Rayleigh-Taylor Instability, the heavier, denser fluid is on top of the fluid that is less dense. If the heavier fluid is carefully positioned, one will notice an interface between the two fluids. The force that acts as a stabilizer is the surface tension, where surface tension from both fluids prevents mixing. However, the second force acting on the system is gravity, which is the driving force for instability. The heavier fluid will want to cause instability due to its weight and cause mixing. For the image captured in Get Wet, the instability is forced by pouring the heavier fluid from a height that wouldn't allow a clean interface between the two fluids. As shown by the Reynolds number and the captured image, the turbulent mixing of the two fluids greatly enhances the Rayleigh-Taylor Instability flow phenomenon.

Visualization Technique

For the visualization of the Rayleigh-Taylor Instability captured in this image, the only materials required for fluid flow aside from the apparatus are coffee creamer, instant coffee, water, and a small dish to pour the creamer from. In order for enough light to pass through the liquid and show the turbulent flow of the creamer, the coffee should be heavily diluted with water. Filling the vase halfway should equate to approximately 130 fluid ounces of water, and 1 tablespoon of instant coffee is enough to give the water a brown color that is still permeable by light. As mentioned before, the only light source in the pitch-black environment is from a fluorescent lamp. The distance from the light source to the bottom of the glass vase is 8 inches. No flash was used for the image. Black cloth is used to cover areas that could be illuminated by the lamp. With two tablespoons of creamer in a small dish, the creamer is poured rapidly to enter the left side of the vase from a height of 30 inches to enhance turbulent flow as opposed to pouring the creamer in slowly with laminar flow. The turbulent entry into the coffee would cause more turbulent flow in the image as a result. Additionally, a height of 30 inches was chosen since the height of the vase is 30 inches. Choosing a lower drop height would have lessened the effect of the Rayleigh-Taylor Instability because the incoming velocity of the creamer would decrease dramatically.

Photographic Technique

Camera Specifications

The field of view of the image has a width of 4.5 inches and a height of 5.7 inches where the width is limited by the diameter of the glass vase. The distance from the object to the lens is approximately 24 inches, which was an appropriate distance to capture the fine details of the flow without capturing too much of the background.

The Helios 44-2 58/2 is a lens with a fixed 58mm focal length and a maximum aperture of f/2. A lens with a focal length of 58mm is chosen because it provides a narrow field of view and large magnification. A shorter focal length would give the viewer the perception that the flow is small in scale, but a longer focal length invites the viewer to perceive the flow as being much larger. The camera shoots in digital format with raw image dimensions of 3906 x 2602, and the final image has dimensions of 2001 x 2536. The camera used for this image is a Canon EOS Rebel XS which does not have flash equipped.

For this image, the aperture is set to f/2 to allow as much light as possible into the camera. Additionally, the shutter speed is 1/80 seconds, and the ISO is 800. A relatively slow shutter speed is used since the images were dark even with an ISO of 800. A lower ISO such as 400 was not chosen because it meant having an even lower shutter speed which produced unwanted motion blur.

Post-Processing

The original and post-processed image are shown in Figure 4. The image is edited first in Photoshop by straightening the image and then cropping the background out. Content-aware is used to remove small bubbles and dents in the glass vase. Next, the curves editor was used to bring out the highlights on fluid surfaces strongly illuminated by the lamp. The rest of the image is darkened slightly through curves so that these highlights become more prominent. Also, the black values were raised slightly and given a green and blue tint. This is intentional because using warm and cool colors together is always pleasing to the eye. Lastly, there is some noise reduction, but not too much where the image becomes blurry.

Figure 3: Post-processed image on the right and the original image on the left.

Conclusion

The image reveals the turbulent mixing of two fluids, which highlights the Rayleigh-Taylor Instability. It reveals an organic-like presence due to the subsurface scattering effect of milk as opposed to transparent liquids like dye. I really like the composition, colors, and uniqueness of the image, and the only thing I dislike is that the image isn't taller to show more information. I fulfilled my intent of visualizing the unique interaction between creamer and coffee. To take it further, a high-speed video of the turbulent mixing would improve this concept tremendously.

References

[1] "Density." The Physics Hypertextbook., Web. 22 Sept. 2015. <http://physics.info/density/>.

[2] "Viscosity of Foods." *Viscosity of Foods*., Web. 22 Sept. 2015. <http://www.engineeringtoolbox.com/absolute-viscosity-foods-d_1827.html>.

[3] "Rayleigh-Taylor Instability." *Hydraulique Et Mécanique Des Fluides*., Web. 22 Sept. 2015. <http://hmf.enseeiht.fr/travaux/CD0001/travaux/optmfn/hi/01pa/hyb72/rt/rt.htm#begin>.