Oobleck Falling Through Partially Dyed Water

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Purpose

This image was produced for the initial 'Get Wet' assignment for the Flow Visualization course provided by the University of Colorado at boulder. The course functions as multi-disciplinary, catering to engineers, film, and art students alike. This assignment was intended for each unique discipline to explore unfamiliar territories involving fluid motion. The art and film students gain knowledge pertaining to the physics and characteristics exerted by fluids, and the engineers get to use their creative side to visualize what was once just numbers and equations on paper. For this image I was trying to implement oobleck, a mixture of corn starch and water. Originally I just tried shooting oobleck by itself, but I eventually came across the idea of getting a shot of it as it flows through water. My intent was to create an image that would be both visually striking and artistic as well as scientifically intriguing.

Approach

For the set up I had a 6" tall glass filled close to the top with water, in front of a white canvas backdrop. There was direct lighting from above as well as ambient lighting from the room. The camera was propped up on a 2" tall box in order to get a more center shot of the glass. I put in 1 drop of blue food dye into the glass and quickly after I poured a small portion of the oobleck into the glass. The setup can be visualized from the diagram below.

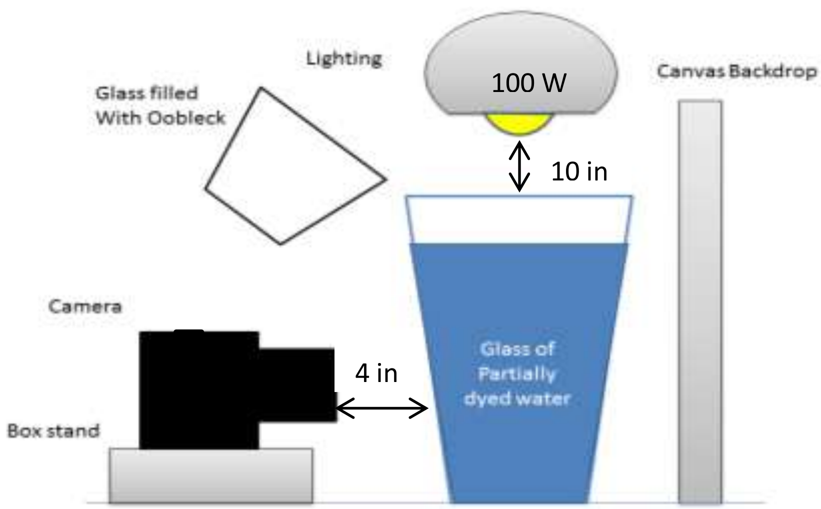

Figure 1: Image Set Up

The oobleck was dropped from approximately 10 cm above the water surface with relatively low speeds due to its higher viscosity but at a high volume, about 4 oz. of liquid. This image represents a Taylor-Raleigh Instability, commonly referred to as "umbrella" instability. As the dye impacted the water at low speed its slightly higher viscosity caused it to disperse through the water in an interesting pattern as it fell due to gravity. As time passed the dye diffused more thoroughly leaving only a few remaining parts of water entirely clear. After the dye had diffused a little the oobleck was introduced recreating a similar effect as the dye in water except in this case it created more a flume shape.

Oobleck is a Non-Newtonian fluid, which acts differently than most fluids. A Non-Newtonian fluid can't be described by the Navier Stoke Equations and differs from Newtonian fluids by how it behaves under shear stress [1]. The image below shows the relations between a Newtonian fluid and a non-Newtonian fluid.

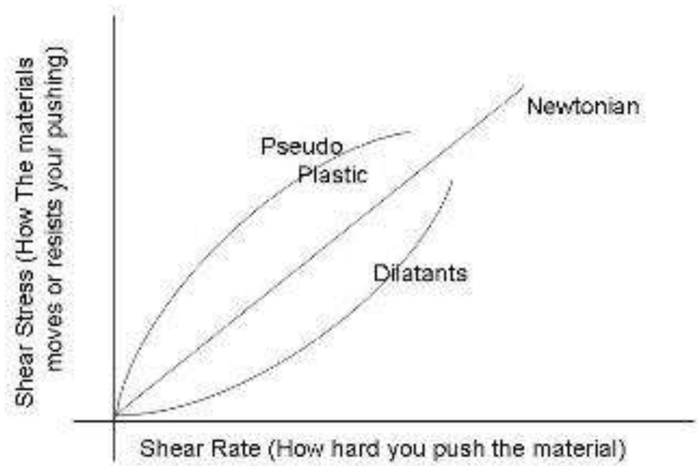

Figure 2: Newtonian and Non-Newtonian Fluids [3]

From the graph it is easy to notice that the force on a fluid is linearly proportional to the shear stress on that fluid for Newtonian fluids. This is different for oobleck, it acts as a pseudo-plastic which acts as a liquid under normal conditions and a solid as a force is applied. This makes it a very interesting fluid to study.

To properly understand the fluid phenomena occurring we must also understand the physics at hand. A common tool used in understanding fluid flow is the Reynolds number. It helps us understand how a fluid will move in a pipe, for this example a glass filled with water. The U is average velocity of the fluid, D is the diameter of the glass, and v is the kinematic viscosity of water at room temperature.

$$Re_{oobleck} = \frac{interial\ forces}{viscous\ forces} = \frac{UD}{v} = \frac{\left(\frac{.01m}{s}\right)(.1016\ m)}{\left(.801x10^{-6}\frac{m^2}{s}\right)} \approx 1268$$

From this calculation we can see the Reynolds number is fairly large so the liquid will spread out very quickly which you can see occurring in the photo. As the two fluids of various densities collide depending on the Weber number they will create a jet or just smoothly flow into one another, in this case, the Weber number is low causing the oobleck to glide into the water with no splashes.

As the fluids mix, their different densities become apparent and the oobleck begins to spread out and "finger", this is known as Rayleigh-Taylor (umbrella) instability. This occurs when a heavy fluid is accelerated by a light fluid [2]. Since oobleck has the much higher density it is apparent that it will sink, so the water pushes it down to the bottom as various pressure forces and gravity also push on the impinging fluid. A set of criterion can be established at the onset of the instability between the interface of the two fluids. If the heavy fluid pushes the lighter fluid, the interface is stable. If the lighter fluid pushes the heavy fluid, the interface is unstable [4]. In this case our interface is unstable since the water is pushing on the oobleck.

Visualization Technique

The primarily visualization technique was oobleck which is a Non-Newtonian fluid, a mixture of 2 parts corn starch and 1 part water. This substance has some very unique properties, acting as a fluid under normal conditions, but when a force is applied the liquid, its viscosity changes and it begins to act more like a solid. When poured into the water it clearly exhibits a more liquid type behavior. Also used was blue dye, not diluted at all, just one drop in the glass allowing for slower diffusion but strong intensity of color. This helped differentiate the white oobleck from the white background. The lighting used was a single 100 Watt fluorescent bulb about 10" above the glass as well as ambient lighting from the overhead lights in the kitchen about 6' above the glass. The white canvas behind the glass helped amplify the contrast of the image. The camera's flash was not used at all.

Photographic Technique

The camera used was a Nikon L105 12.1 mega-pixel super zoom digital camera with a 15x optical zoom. The camera lens was approximate four inches from the glass and propped up about two inches to get a more center shot and creating a field of view about 6" x 5". The IS0 was on automatic, and it was set to sports continuous mode which produced a shutter speed of approximately 1/25th of a second. This allowed me to capture multiple images as the fluid fell through the water while minimizing blur, it also let me select the best picture that represented my intent out of the 20 images shot. The F-stop was approximately 3.5 to let in enough amount of light. The original image can be seen below which was 2048 pixels wide by 1536 pixels tall.

Figure 3: Original Image

Using Adobe Photoshop CS5 I adjusted the contrast to enhance the dark colors, and inverted the colors to create a bolder image. I used the clone stamp tool to eliminate a reflection of the word Nikon in the glass which you can barely see in the impact ring. And finally I cropped it and to add an interesting element to the image I rotated it by 180 degrees making the final image 1234 x 1103 pixels. It was my first time using Photoshop as well so my capabilities were greatly limited, but I feel I was able to create a powerful image with the tools at hand.

Conclusion

Overall, I really like this image. It captures a moment in time in fluid phenomena that would otherwise be lost by the human eye alone. I enjoy both the original and photo shopped image as they both bring something appealing to our perception. My intent was visualized and even surpassed, this beautiful image was created off something I was not sure would even work, so I am very pleased with the results. This is my first time trying to explore the capabilities of a camera and understand all of the elements at play to create an image so I feel that I learned a great deal from this first assignment.

[1] T. Koide, Non-Newtonian Properties of Relativistic Fluids. Pg. 1-2. 2010
[2] K.S. Budil, Classical Rayleigh-Taylor Instability Experiments at Nova. Pg. 4. 1997
[3] http://www.dispensetips.com/pages/rheology.html
[4] D.H. Sharp, An Overview of Rayleigh-Taylor Instability. Pg. 5. 1983