Visualizing the Fluid Dynamic Properties of Oobleck, a non-Newtonian Fluid

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1. Introduction

Generic corn starch and water independently have very simple and well known properties that follow a linear Newtonian relationship, specifically where they both follow Newton's 3rd Law of Motion. However, once these two simple components are mixed to form oobleck, they take on this fascinating complexity that completely changes their relationship to the forces acting on it and transforms into a fluid that no longer observes Newton's 3rd Law. To further understand this complexity, oobleck was stimulated by a rapid force and the results were captured in various images by Rachel Grosskrueger and Vincent Staverosky. The intent was to capture the motion in a way that would visually provide and understanding of the fluid dynamic properties of oobleck. The motion of this non-Newtonian fluid could be best visually represented when stimulated by a rapid force, specifically a speaker set at various frequencies to show the many viscous properties. It was desired to closely examine the resonate frequencies of the oobleck in reaction to the applied frequency from the speaker. Through multiple trials, it was found that the oobleck will form standing waves in response to a lower frequency sound wave. Unlike the standing waves of a Newtonian fluid, these waves are not uniform and seem to happen in no particular pattern or order.

2. Methods and Discussion

The setup used for operation consisted of a twelve inch speaker, plastic glad wrap, a low-pass amplifier, a laptop, a simple desk lamp with a 100 W black light bulb, the Cannon T3i camera connected to a tripod, a black sheet, cornstarch, and tonic water. The oobleck mixture was one part tonic water, two parts cornstarch. Plastic wrap was tightly stretch across the outer diameter of the speaker and secured using duct tape. The oobleck was then poured on the surface of the plastic wrap. The black light bulb was approximately one foot above and one foot to the right from the center point of the oobleck. In order to operate the speaker, it was connected to a low-pass amplifier where frequencies were run through the laptop using an online frequency program. In the image, the frequency was set at 30 Hz with rapidly fluctuating amplification. The camera was set three feet away and two feet above the surface of the oobleck. The black sheet was used as a backdrop to create a sold black background in order to emphasize the color intensity under the black light. See figures 1 and 2 for visual.

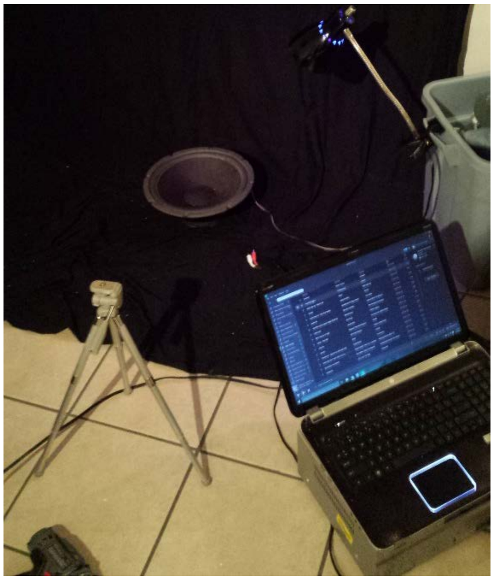

Figure 1

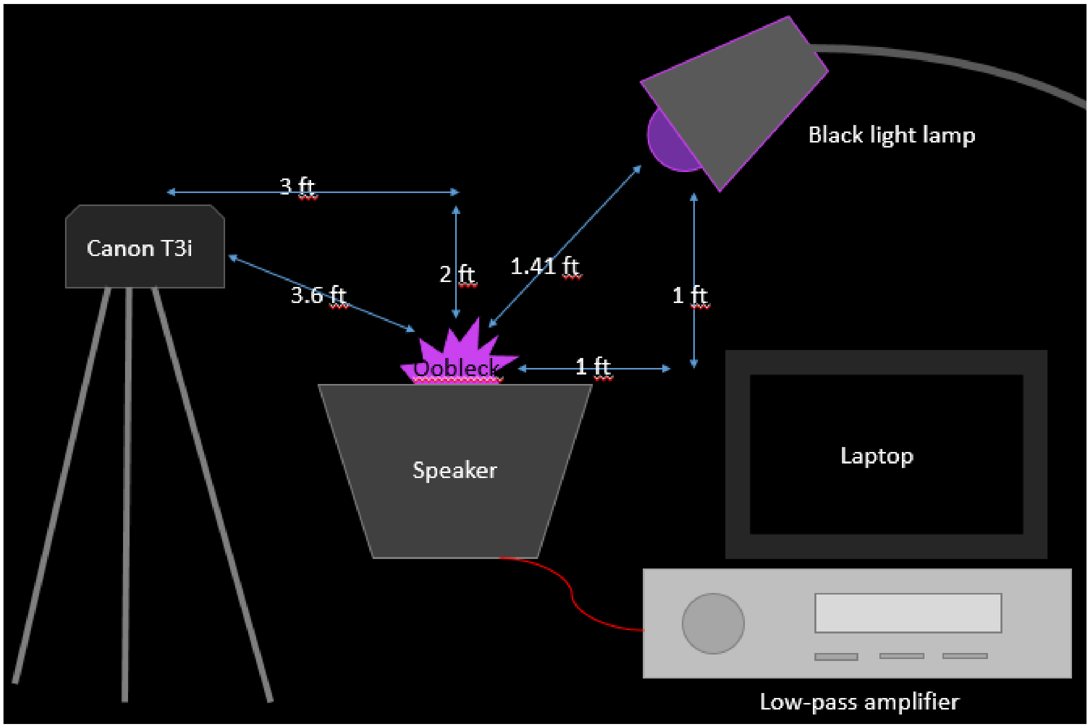

Figure 2

Once activated by the frequency, the oobleck would "crawl" on the surface of the plastic wrap and form various standing waves, ripples, finger-like protuberances, and threads with bead-like drops accelerating from the tops. The flow was very random and as each type of wave formed they would either vibrate, crawl, or jump around the surface of the speaker. To further understand this behavior, it is necessary to examine how a speaker operates and the interaction oobleck has with various forces.

To start, oobleck is a non-Newtonian fluid but more specifically a stress thickening fluid or dilatant fluid. When a large or sudden force is applied, the cornstarch molecules flocculate resulting in the mixture to take on a solid-like state. This phenomena is what physicists call a "sideways shearing force". When the force is applied, the water is "squeezed" out from the cornstarch particles and the friction between the cornstarch particles dramatically increases. The result is an increase in viscosity and a process known as dynamic solidification. When oobleck is at rest, the cornstarch particles are surrounded by water which acts as a lubricant. The surface tension of the water allows for this to occur and prevents the water from pooling or separating from the cornstarch. The viscosity in this case, is much like that of water and is significantly lower than the previous state detailed above. Oobleck does not have a constant viscosity and constantly changes depending on the forces acting on it, the ratio of water to cornstarch, and temperature. Therefore, a Reynolds number cannot accurately describe the flow patterns of oobleck. Reynolds number is used to predict flow patterns of various fluids and expresses the ratio of a fluids ability to resist change or motion to its viscosity. It could be possible to calculate a Reynolds number for the resting state and another Reynolds number for the higher viscous state. However, the Reynolds number calculated at either state cannot predict the motion of the other and is therefore rendered useless. Additionally, viscosity of a non-Newtonian fluid is dependent on shear rate. In a non-Newtonian fluid's shear stress and shear rate is not a linear relationship (which it is in Newtonian fluids) and can be time-dependent as seen in figure 3. Therefore, a constant coefficient of viscosity cannot be defined. The same argument can be made regarding the Grashof number which relates the buoyancy of a fluid to the viscous forces.

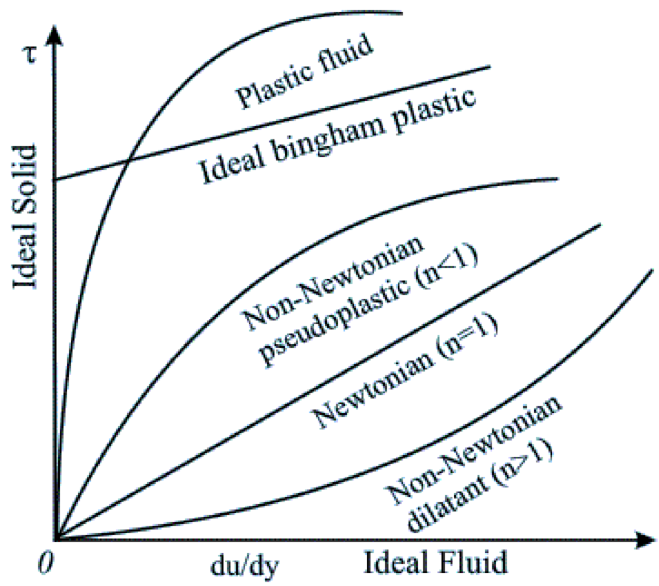

Figure 3: Shear stress and deformation rate relationship (NPTEL)

In order to analyze the behavior of the oobleck in this setup, it is beneficial to examine the dynamics of a speaker. When a speaker is playing sound, the speaker moves back and forth, transmitting kinetic energy to the air particles which causes a fluctuation in the air pressure. At lower frequencies, the vibrations are slower. Another important detail is that the larger the speakers are, the greater the potential to move more air due to the increase in surface area.

The combination of the oobleck and the speaker results in various types of waves and behavior. At higher frequencies, the force is too abrupt and causes the oobleck to splatter and jump completely off the speaker in a chaotic manner. At lower frequencies, the oobleck will form anything from rippling waves to standing waves that have the "crawling" effect.

3. Visualization Technique

Traditionally, oobleck is made using cornstarch and regular tap water. The purpose of using tonic water was to create an improved interaction with the black light. Tonic water has the chemical quinine dissolved in it which is fluorescent under a black light. Use of tonic water improves the fluorescence of the oobleck when compared to regular tap water. The glowing oobleck against the solid black background allows for a more dramatic color intensity in the image. To further support the desired effect, the only sources of lighting in the setup were from the black light and the camera flash. The setup was performed in the basement of Vincent's house using his speaker, low-pass amplifier, and laptop. The other materials were purchased from local stores. Specifically, the tonic water, corn starch, and plastic wrap were purchased at a general grocery store (King Soopers), the black light was purchased at Home Depot, and the black sheet was purchased at Target.

4. Photographic Technique

The intent for the image was to clearly represent the phenomena occurring and include as much detail as possible. The purpose of the black light setup was to clearly illuminate all features of the white oobleck and eliminate any loss of information that potentially could have come from a white light or white background. All post processing done in photoshop also was done with this same approach and was intended to improve the overall contrast of the image and bring out any detail that was less apparent in the original image.

With this goal in mind, the Canon EOS REBEL T3i settings were placed at an F-stop of f/5.6, an exposure time of ¼ second, maximum aperture of 4.625, an ISO speed of 1600, and a focal length of 116 mm. The size of field of view was 8 ½ inches wide and the oobleck was approximately 3.6 feet away from the lens of the camera. With these settings, the original image was 5184 x 3456 pixels in size. The lens used was the cannon zoom lens with a focal length ranging from 55-250 mm and the F-stop range of f/4-5.6 with image stabilizer. The original unprocessed image is shown in figure 4.

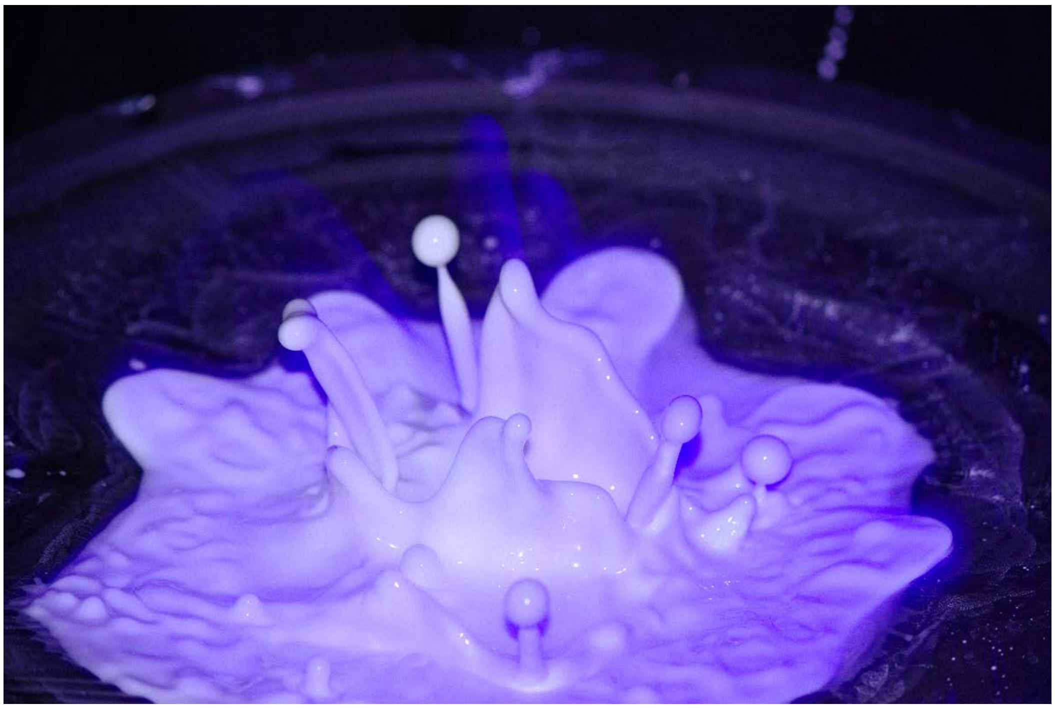

Figure 4

To enhance the image and improve the color vibrancy, post processing was performed in photoshop. Once in photoshop the following manipulations were made, the image brightness and contrast were adjusted to -35 and 26 respectively, exposure was adjusted to +0.44, offset to -0.0207, and gamma correction to 0.85. The vibrance was set to +8 and the saturation level was at +10. The hue level was at -2, saturation at -4, and lightness at -7. And finally at 1% a d58900 color photo filter was added. The final post-processed image dimensions were 4184 x 2392 pixels. All these modifications were implemented with the intent to show more detail in the image as well as provide a pleasing contrast to the image in a way that emphasizes the flow and dynamic properties of oobleck.

5. Conclusion

The image does a great job showing the fundamental properties of oobleck. Essentially it captures multiple aspects of the interaction with a resonant frequency. The outer diameter of the fluid forms rippling waves with smaller reactions to the stimuli, whereas at the center of the speaker, where the frequency and vibrations are most heavily concentrated applies a more dynamic shearing force which directly reflects that impact. It is very clear to notice the water like motion of the outer ripples when the forces are lower and have minimal impact on the viscosity. Contrastingly, it is also just as apparent where the forces are great enough to increase the viscosity and form the solid-like standing waves in the center of the speaker. The final image shows the two dissimilar fluid motions of a dilatant non-Newtonian fluid.

Something that could be improved upon in the final image would be to eliminate the "ghosting" shown by the blue wisps at the top of the image. It tends to be a slight distraction from the phenomena that the image is portraying. To further develop the concepts captured in this image, an overhead video or image could prove to be very revealing. This different perspective could demonstrate the nonconcentric patterns at the outer edges of the fluid in a clearer way as well as show where the sprouting threads form and if it is in a concentric or random manner. This overhead shot could provide more information on the chaos/randomness of the standing waves and potentially show possible patterns or consistencies in the types of waves formed and the location relative to the center of the speaker.

6. References

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