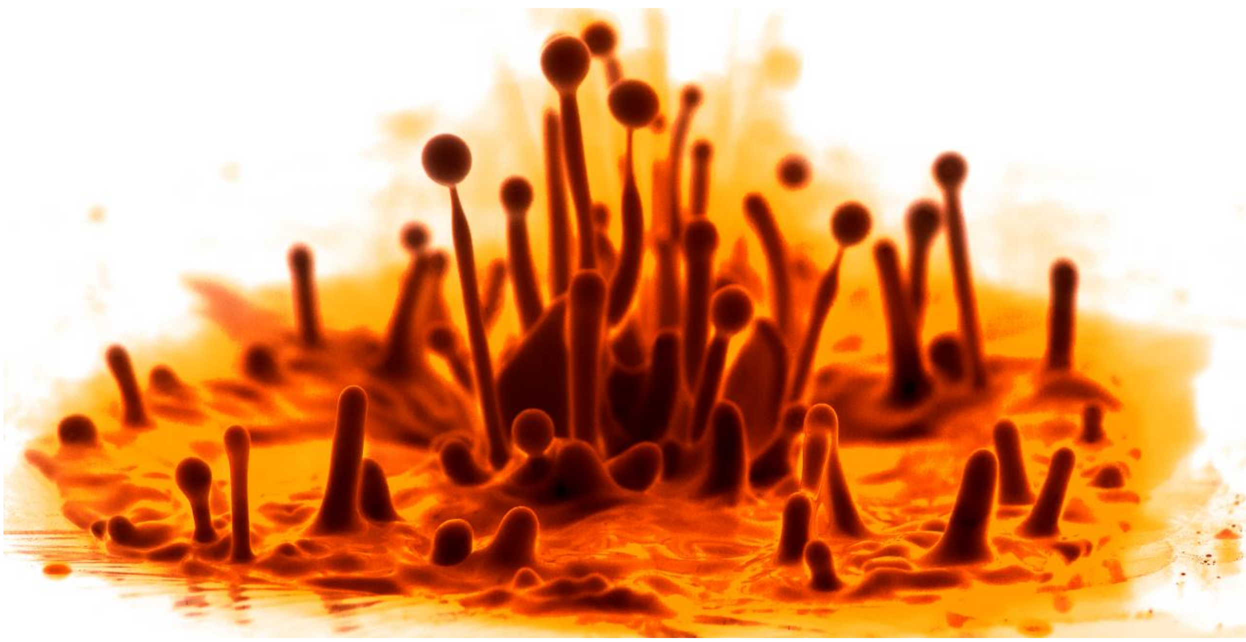
Oobleck on a Speaker



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Get Wet Report
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Prof. Hertzberg
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Introduction

This image was produced for the initial ‘Get Wet’ assignment for the Fall 2015 Flow Visualization course offered in the University of Colorado School of Engineering. The objective of the assignment was to produce an aesthetically appealing image that captures a particular physical phenomena that can later be analyzed. The intent of the experiment behind this image was to examine the dynamics of a non-Newtonian fluid that has been excited by acoustic waves. In other words, the goal was to see what happens when oobleck, a suspension of corn starch in water, is placed on a speaker that plays various sounds. Originally, the attempt was made to fluoresce the fluid by mixing tonic water with the corn starch and illuminating it with a black light. Unfortunately the low light level was not conducive to achieving a time-resolved image. In the end, a flash was used to freeze the motion of the oobleck. The experiment was conducted on 7 September 2015 in cooperation with Rachel Grosskrueger.

Observations

The setup for this experiment involved covering a 12 inch speaker driver with a sheet of plastic wrap to protect the speaker and pouring a sample of Oobleck onto the plastic wrap. See Figure 1 for a rough sketch. A variety of sounds were then played from a laptop, through an amplifier, and finally through the speaker. Music played through the speaker did not produce a consistent effect so an online tone generator was utilized. After some experimentation it was clear that the optimum frequency for generating the most interesting bursts of activity was 30 Hz. A constant 30 Hz tone was played as the gain on the amplifier was rapidly modulated to increase the level of excitement within the fluid. This caused the significant amount of splash seen in the image.

Figure 1: Experimental setup of the speaker

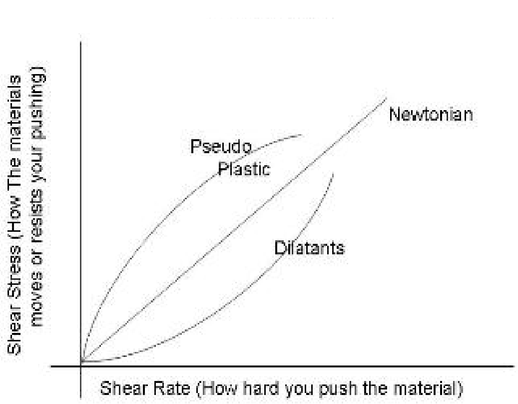

Figure 2: Newtonian and non-Newtonian fluids

Any standard level fluid mechanics class focuses on the majority of situations encountered in real life, i.e. those involving Newtonian fluids – fluids that have a linear stress-strain rate correlation which makes their behavior simpler to predict. As a non-Newtonian fluid, the oobleck does not fit nicely into such a curriculum. Specifically, it is considered a shear-thickening (dilatant) fluid, meaning that viscosity increases and the fluid thickens when a shear stress is applied. Figure 2 gives a visual representation of the differences between the two stress-strain rate curves.

Unfortunately, due to their rare nature, there is not much literature on the behavior of non-Newtonian fluids. However, it is interesting that the oobleck appears to be exhibiting behavior similar to that of a Worthington Jet. Typically, a Worthington Jet is produced by an object impacting a pool of liquid, causing a cavity to form that subsequently collapses due to the pressure of the liquid acting on it. The collapse causes a jet of fluid to shoot upward. But without the impact of the droplet, how are the cavities being formed?

This phenomenon can be linked to Faraday instability. In liquids, this instability causes patterns of standing waves that correspond to the vibration frequency that is used to drive the flow. As the vibration amplitude increases above a particular threshold, the oscillation of the waves exaggerates and creates cavities within the fluid. These cavities then collapse into singularities, subsequently producing jets of fluid that eject upward.

The image also nicely captures the effect of surface tension. This tension helps draw the spires back down into the pool faster than gravity pulls the drops at their tips. Several drops are caught mid release, beginning to form perfect spheres. In addition, there is an interesting peculiarity in the undulations of the spires of the jets.

Both the undulations and the droplets are the result of the Plateau-Rayleigh instability which is driven by surface tension. Due to the fluid's surface tension, it naturally tends to minimize its surface area for a given volume. Since spheres have the lowest area-to-volume ratio, the fluid will form perfect spheres in the absence of external forces. The undulation of the jets, then, is simply an intermediate phase of their breakup into these droplets. If a thicker mixture were used, the oobleck would be expected not to show such dramatic breakup behavior because the increased viscosity would dampen out the surface perturbations that cause the jets to separate into droplets. The behavior would be analogous to that of honey, which forms smooth streams of fluid when poured.

Furthermore, it is particularly fascinating to note that while there is much activity in the center of the pool of oobleck, there is an accompanying ring of lesser activity around the edge of the pool with a relative dead space in between. In the future it could prove valuable to extend the scope of the experiment to include high speed videography in order to determine the time dependence of the observed phenomena.

In fact, this phenomenon may also be the result of Faraday instability. As Harris & Bush from the MIT Department of Mathematics illustrate, this pattern of intense activity at the center surrounded by alternating rings of calm and lesser activity bears semblance to a Faraday wave mode.

Visualization Technique

The oobleck started out as a fairly thick mixture and was thinned over time by adding additional tonic water. Due to poor planning, there was not enough forethought to take into consideration the exact proportions of each ingredient. The experiment was set up in a dark room, void of external light sources. The supplied light was from a desk lamp outfitted with an incandescent "black light" in addition to a flash. The bare flash of the camera was diffused slightly by the use of a facial tissue.

Photographic Technique

Figure 3 shows the original image. It was photographed with a Canon EOS REBEL T3i with resolution 5148 x 3456 pixels. This was the largest available setting at about 18MP, used to capture as much detail as possible. The field of view for this image was also selected with detail in mind, cutting out unnecessary backdrop. From edge to edge along the width of the focal plane, the image spans approximately 8 inches. The lens had a 123 mm focal length and was set to the 'macro' zoom setting. The camera was mounted on a tripod approximately 3 feet away and about 1 foot above the pool of oobleck as show in Figure 4 (see next page).

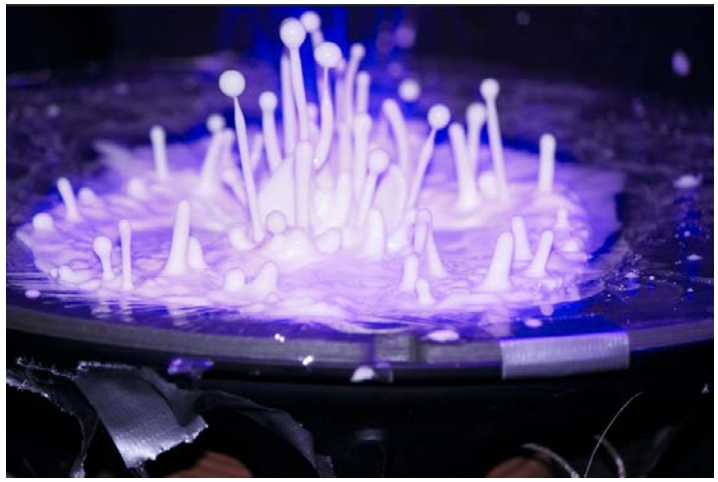

Figure 3: Original image

Figure 4: Experimental setup, including camera, speaker, amplifier, laptop, and lighting (black light bulb used when original image was taken)

The exposure settings were as follows: f-stop = f/5.6, exposure time = ½ second, ISO speed = 1600. At the time that the original image was taken, a black light bulb was used in the lamp, giving the image its purplish hue. The selected exposure settings were originally an attempt to capture the flow in low light but when the image was still too underexposed the flash was added. The resulting photo turned out surprisingly clear, even though focal plane was further forward than expected.

The raw original image was modified in Photoshop CS6 to achieve the final product. The first modification was an increase in contrast to make the edges of the splashed fluid more dramatic. The colors were then inverted to draw attention to the center of the image. Unfortunately, this created a number of ugly artifacts resulting from the white-saturated pixels caused by the flash. These artifacts were erased using the clone tool and then the final color was adjusted to give the red tones instead of green. After editing, the photo was cropped down to 4616 x 2336 pixels, slightly altering the aspect ratio.

Take Away

After post-processing, the image ultimately turned out quite well and clearly expresses a number of interesting physical phenomena. It also achieves a strong aesthetic appeal, which was the main motivation for pursuing this particular experiment in the first place. It was particularly enjoyable to find that the artistic liberty taken in the processing of the image resonated well with the class audience and elicited a number of interesting reactions. The result of the overall experiment, however, does leave a number of unanswered questions concerning the nature of the flow. Was it actually behaving in an observably non-

Newtonian fashion? If the fluid should thicken when subjected to an outside force, why does the center of the pool jettison out the most rather than harden the most? Is there a point when adding enough water to the mix causes it to cease its non-Newtonian behavior? In the future it would be fascinating to introduce independent variables such as different oobleck mixture ratios and different frequencies/amplitudes of the sound. It might also be valuable to design a different experiment to determine the stress-strain rate curves for different mixtures and try to correlate that to phenomena observed in the speaker experiment.

Bibliography

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