Non-Newtonian Fluid Visualization

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Team First Assignment: Flow Visualization MCEN 5151

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Introduction

The intent of the submitted photograph was to visualize, both artfully and demonstratively, the alien behaviour of non-Newtonian fluids. The photograph was intended for the third assignment of the Flow Visualization class at CU Boulder. The image produced was created with the help of a fellow student Andrew Locke. The specific phenomena examined in this photograph is the propagation of pressure waves through corn starch and water. A speaker was covered in plastic cling wrap then filled with a mixture of cornstarch and water. As the speaker was turned on the vibrations would cause quick intense pressure wave propagation through the medium causing the fluid to solidify into smooth shapes as can be seen in the final submitted photograph.

The idea for this shot is not unique and came from the research of multiple similar experiments. Non-Newtonian behaviour, while unexpected, is a well researched and documented phenomena and using a speaker is a common visualization technique.

Flow Apparatus

The setup for this photograph was simple and many example of similar procedures could be found on-line. A speaker was laid down and a food tray, lined with a mixture of 2 cups cornstarch and 1 cup water (oobleck), was vibrated using music played through and the speaker with an amplifier.[1] This initial setup can be seen in figure 2.

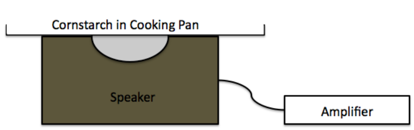

Figure 1: Initial Setup

The idea was that the speaker would vibrate the tray sending pressure waves through the oobleck causing the fluid to produce shapes and change form, however this initial setup produced questionable results. To rectify the situation 1 half cup of the same oobleck mixture was layed inside of the speaker which had been lined with cling wrap. This was in an attempt to ensure non-damped pressure wave propagation through the oobleck and in the end produced the image submitted. This final setup can be seen below in figure ??.

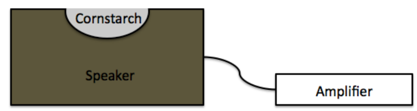

Figure 2: Final Setup

The factors which needed to be controlled for this experiment were the volume of oobleck used, and the magnitude of the pressure waves transmitted. The volume of oobleck was decided to be 1-cup as to prevent damage to the speaker from too much weight, and to provide enough medium to produce a decent photograph. In order to get a variety of pressure waves, a song was played through the speaker and overall volume was adjusted to change the magnitude.

In order to create the best visualization multiple camera angles were explored. Overhead shots were determined to lack depth of field, and so a slightly down turned side view was decided upon as it provided the best contrast and image clarity.

Flow Analysis

The visualized phenomena is governed by an increase in viscosity when shear stresses are applied. The combination of cornstarch and water is known as a "dilantant" or shear thickening fluid. Dilantant fluids are colloidal suspensions, which when stationary are stable but transition into states of flocculation when a high shear rate is applied. In this image the vibrating speaker transfers shear stresses rapidly into the dilantant fluid which causes the viscosity to increase[2]. This increase in viscosity allows for the propagation of pressure waves from the speaker forcing the fluid to take shape. The high viscosity also ensures that there is no separation between the fluid into droplets as there would be with water on a speaker. The relationships between shear stress and shear rate for

Non-Newtonian fluids and Newtonian fluids can be seen below in figure 3.

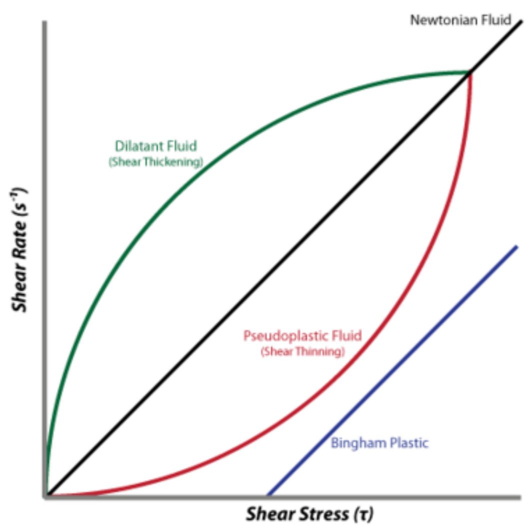

Figure 3: Shear Rate vs. Stress for Different Fluid Types[3]

In order to fully understand what is happening the equations for viscosity and shear for both Newtonian and Non-Newtonian fluids need to be examined. For a normal Newtonian fluid shear stress and shear rate are related as follows:

$$\tau = \mu \frac{du}{dy} \tag{1}$$

Where τ is shear stress, μ is viscosity and the quantity $\frac{du}{dy}$ is the velocity gradient of "shear rate". For a normal fluid μ is a constant and thus the relationship between stress and shear rate is a constant. However, when viscosity becomes a function of the shear rate this relationship changes, and the phenomena observed can occur.

Viscosity of a fluid (both Newtonian and Non-Newtonian) is given by the Ostwaldde Waele power law as pictured below.

$$\eta = K \frac{du}{dy}^{n-1} \tag{2}$$

Where η is the viscosity K is a material constant of the fluid. For normal Newtonian Fluids n=1 thus forcing the shear rate quantity to 1. If a material is a dilantant then n is greater than 1 and the viscosity depends on the shear rate. Bringing this back to the original equation for shear stress in fluids equates to the equation below:

$$\tau = K \frac{du}{dy}^{2} \tag{3}$$

This results in the thickening effect visualized as the shear rate is increased by a speaker vibrating for example.

Non-Newtonian "thickening" fluids have many practical applications in modern technology as well. For example, a lot of industrial applications where high torques are needed to be applied slowly this type of fluid is perfect. If you have one rotating shaft and need it to transfer power slowly to another stationary beam without a clutch, this type of fluid, if placed between the two shafts, will increase in viscosity and then apply the shear you need to transfer that energy slowly.

Visualization Technique

For good visualization the scene had to be designed in a manner to provide good lighting and minimal reflection. The largest challenge with the photo was reducing glare from the cling wrap while still allowing enough light for a fully exposed image. This was accomplished by using a black back drop and two independent lighting sources. Both lighting sources were dimmed with the use of white printer paper, and the black drop was made of non glossy fabrics which would absorb light quickly and effectively. This allowed the scene to be lit while eliminating most glare.

Photographic Technique

The quick propagation of pressure waves induced quick changes to the shape and form of the oobleck and thus a fast shutter speed was desirable. After reducing the f-stop to f/5.6, and raising the ISO to 800 a shutter speed of 1/400 s was available. This fast shutter speed eliminated blurring in the image, and while the high ISO produced some small noise in the image, this was deemed acceptable.

The purpose of this photo was to focus on the odd forms which oobleck can take, while still giving insight into the experimental setup. To keep the oobleck as the focus of the image the camera was placed to the side of the setup and then tilted downward so that the setup could be visualized as well. For reference the submitted photo was taken with a Canon EOS Rebel Xsi DSLR. This resulted in a 4272 X 2848 pixel resolution.

Conclusion

The submitted image was intended to give good insight into the odd behaviour of non-Newtonian fluids when subjected to stress. The contrast between the smooth form of the oobleck and chaos of the surrounding cling wrap provided good contrast, while still keeping the fluid as the main focus. The odd behaviour is clearly visualized and this visualization gives good insight into the underlying physic.

As always there are small issues with the photograph mostly coming down to lighting. While the image is clear, in focus, and shows no signs of motion blur, the noise induced by the high ISO could be reduced. It is possible that with the addition of a third light source the ISO could have been reduced while keeping the shutter speed at an acceptable level.

Overall, I am proud of this image and feel it was a good visualization of an uncommon occurrence. I look forward to future projects and opportunities to further my abilities as a photographer.

Bibliography

1. "Housing a Forest." Housing a Forest. N.p., n.d. Web. 16 Mar. 2013. http://www.housingaforest.com/dancing-oobleck/.
2. "Oobleck: The Dilatant Fluid." News. N.p., n.d. Web. 08 Apr. 2013. http://mech2262.drupalgardens.com/content/oobleck-dilatant-fluid.
3. "Shear Stress Vs. Strain Rate." Wikipedia Commons, 21 May 2011. Web.