Group Project #3 – Non-Newtonian Fluid Impact Reaction

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Purpose

The purpose of this image is the third group project for MCEN 5151: Flow Visualization, taught by Professor Hertzberg at the University of Colorado at Boulder in Spring 2012. The image is meant to adequately show and demonstrate a fluid flow that can be physically explained in the accompanying report. The image shows a comparison between an object impacting a non-Newtonian fluid and a Newtonian fluid under the same parameters.

Materials

The image was created using all commonly used materials, save for the camera, which can be found at any Target® location. The materials are as follows:

1. Wine glasses
2. Golf balls
3. Water
4. Corn starch
5. Nikon D40X Digital Camera

Procedure

The apparatus used to create the image is as shown in Figure 1, below.

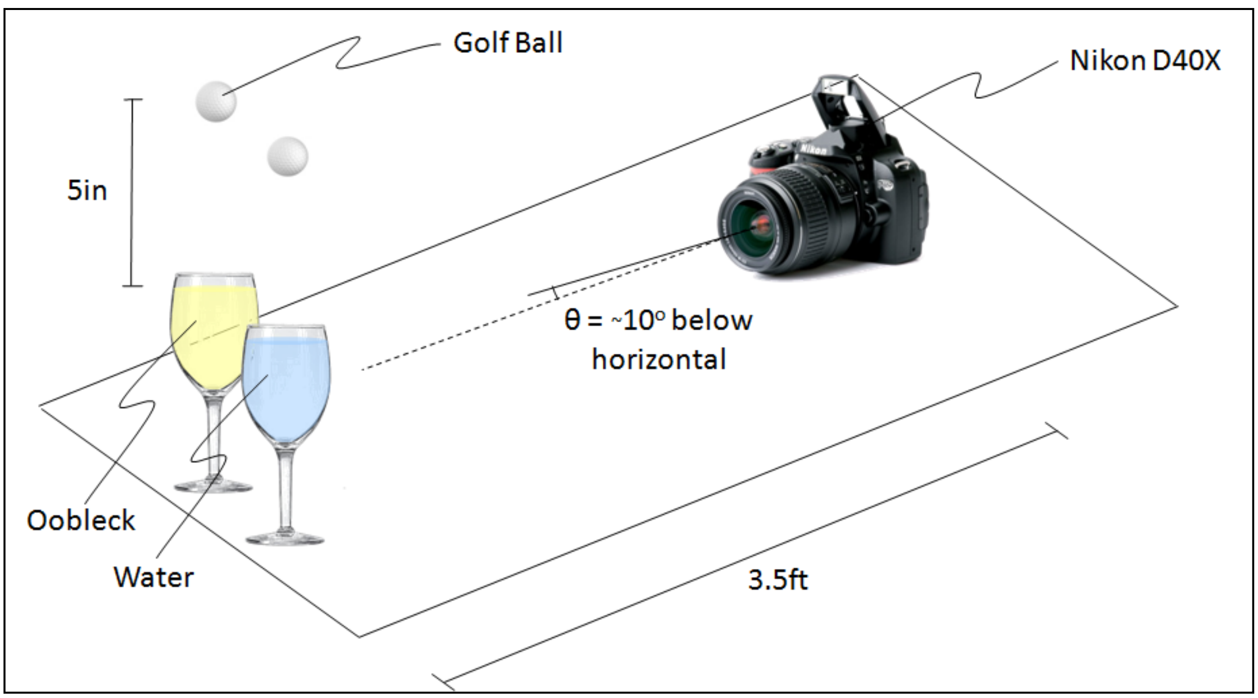

Figure 1: Experimental Setup

The apparatus for this image is very simple. It consists of four components: 2 golf balls, a wine glass filled with Oobleck, a wine glass filled with water, and a camera. The two wine glasses are side-by-side and are filled almost to the brim with their respective liquids. The camera is focused on the top surface of the liquid from 3.5 feet away. A standard golf ball is dropped into each liquid from a 5in height at the same time. The image was captured the instant after the balls impacted the surface of the liquids. The Oobleck that is used is 3 parts corn starch to 2 parts water that was mixed into homogeneity. The image was taken outside at night with an incandescent lighting source as well as a camera flash.

Fluid Dynamics

Oobleck is a colloidal suspension of corn starch in water and falls into a special class of non-Newtonian fluids called Dilatants, or Shear Thickening Fluids. These fluids exhibit increased shear viscosity with applied shear stress. This happens because the fluid crystallizes under stress, therefore behaving more like a solid than a liquid[1]. The parameters that dictate shear thickening behavior include particle size, distribution, shape, particle-particle interaction, and type and rate of deformation[2]. The Power Law equation indicates the viscosity of a solution as a function of shear rate.

$$\eta = K\gamma^{n-1}$$

In this equation, η is viscosity, K is a material constant, and γ is shear rate. Dilatant behaviors emerge at $n \geq 1$.

It is because of these traits that the differences between the Oobleck and water become apparent. A golf ball initially at rest dropped from a height of 5in will be traveling at approximately 62in/s when it impacts the surface of the liquid, as shown below.

$$U^2 = 2ay = 2\left(386.4\ {}^{in}/_{s^2}\right)(5in) \rightarrow \quad U = 62\ {}^{in}/_{s}$$

The ball then impacts the surface with a momentum calculated from its speed and mass (a golf ball is set to be 1.62oz, which is 0.00315 slugs, by the USGA)[3]

$$P = mU = (0.00315\ slug)\left(62\ {}^{in}/_{s}\right) = 0.195\frac{slug * in}{s}$$

As the ball hits the surface, the momentum causes an impulse on the surface, which can be calculated using the impulse-momentum theorem, below.

$$I = \int_{t_1}^{t_2} \frac{dP}{dt}dt = \int_{P_1}^{P_2} dP = \Delta P$$

$$I_{Ball\ in\ Oobleck} = \Delta P = P_2 - P_1 \approx 0.195 - 0 \approx 0.195\ \frac{slug * in}{s}$$

$$I_{Ball\ in\ Water} = \Delta P = P_2 - P_1 \approx 0.195 - (0.2)(0.195) \approx 0.156\ \frac{slug * in}{s}$$

The impulse of the ball in Oobleck is approximated as 0.195 slug*in/s, from the observation that when the ball impacts the surface of the Oobleck, it stops momentarily then starts to sink into the liquid. Thus, the momentum of the ball just after impact is zero. The impulse of the ball in water is approximated as 0.156 slug*in/s, from the observational approximation that the ball slows to 20% of its original speed and thus 20% of its original momentum just after impacting the water's surface. The impact differences observed and calculated reflect the fluid properties of both liquids. When the ball impacts the surface of the water, it is resisted by the surface tension of the water as well as its viscosity, but the water quickly moves out of the way of the falling ball and splashes up. This reaction is very common and has likely been observed by almost everybody. When the ball impacts the surface of the Oobleck, conversely, the Oobleck reacts to the shear forces that the surface of the ball are putting on it by crystallizing and completely stopping the travel of the ball. Once the ball is stopped, the shear stresses imparted on the Oobleck by the ball are far less, and the fluid transforms back to behaving more like a liquid, and lets the ball slowly sink into the solution.

The image was taken just after the balls impacted their respective liquids. The splash of the water is captured, as is the slow sinking of the ball into the Oobleck. There is no splash whatsoever of the Oobleck because it turns crystalline upon impact of the ball, and is thus not forced out of the way of the ball and out of the glass as the water is.

Visualization Technique

There was no external visualization technique used in acquiring this image such as dye, smoke, etc. The fluid flow was visible in and of itself. The lighting was provided by a incandescent light bulb as well as the camera flash.

Photographic Technique

The size of the field of view is 5in tall by 7in wide, the glasses were about 3.5ft from the camera lens, which was necessary to accommodate the long focal length lens. The lens had a focal length of 42mm with an f-stop of f/5.3. A Nikon D40X produced a 2560x1713 original image that was transformed to a 2338x1488 final image. The camera settings were a shutter speed of 1/200sec and ISO 800. These were chosen to balance the need to absorb a lot of light because of the darkness of the background but yet have a quick enough shutter speed in order to not have too much motion blur. Post processing was performed on the image using Adobe Photoshop. The clone stamp tool was used to remove two fence posts in the background of the image, and the image was cropped. The result is a simpler, less distracting picture that lets the observer focus more on what is going on with the fluid flow.

Figure 2: Before & After Post Processing

Conclusion

In the pursuit of demonstrating the difference between Newtonian and Non-Newtonian Fluid reactions to impact, I believe that I did a very good job. I really like how clear and simple the final image ended up, as well as how well resolved it is. The core concept of the image is shown very well, as are the fluid dynamics. The intent of the image was fulfilled, and in the future I would like to take a video of the same comparison, as opposed to a single image.

References

1. Coleman, Paul C. Painter, Michael M. (1997). *Fundamentals of polymer science : an introductory text* (2nd ed. ed.). Lancaster, Pa.: Technomic. pp. 412–413. ISBN 1-56676-559-5.
2. Galindo-Rosales, Francisco J.; Rubio-Hernández, Francisco J., Velázquez-Navarro, José F. (22 May 2009). "Shear-thickening behavior of Aerosil® R816 nanoparticles suspensions in polar organic liquids". *Rheologica Acta* **48** (6): 699–708.
3. "Mass of a Golf Ball." *Mass of a Golf Ball*. Web. 08 May 2012. <http://hypertextbook.com/facts/1999/ImranArif.shtml>.