Alexander C. Thompson

University of Colorado

MCEN 5151

Team Third, Fall 2016

Introduction

This assignment was once again to find an inspiration in real life, capture it in an image or video, and report on the fluid mechanics and physics at play with your teammates. Daniel Luber, Tiangen Ge, and I decided that the last team event should be something fun to wrap the semester up in great fashion. Daniel brought up the idea of experimenting with latex paint in a tank of water. His inspiration was originally Professor Tadd Truscott's presentation on paint, then a fellow student, Harrison Lien, did a similar project for his second team assignment, which turned out well enough that we tried to mimic his set-up.

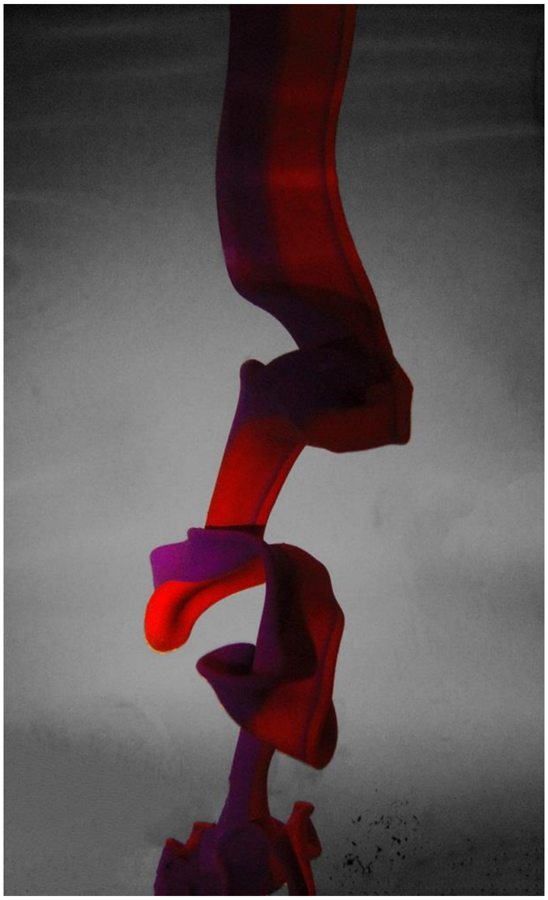
Figure 1: Final Image for Third Team Assignment

So that's what my team decided to do. The three of us got together at Daniel's apartment on the night of Monday, November 28, 2016; Daniel had bought six different colored sample cans of Behr paint. We also borrowed Professor Hertzberg's glass fish tank, the dimensions of it were about 1' x 3' x 1'. As it turns out, in order to get an image I was truly proud of, it took more time and effort than originally expected. We were all inspired by the colorful plumes and ribbons that would develop in the water when the paint was poured in, but it took many trials to get the images to look just the way we wanted.

The Physics and Fluid Mechanics behind the Image

The required ingredients to recreate this image were two cans of Behr latex paint, tap water, and the fish tank mentioned above. I tried to mix the two colors of paint lightly, still keeping the two colors separated at a seam in the middle, in a square Tupperware dish. The fish bowl was set on the breakfast bar and filled 75% full with tap water out of the extendable faucet. Then we allowed it to rest a minute to calm the bubbles. Then a white background was set behind the tank as a backdrop. Tiangen dipped a wooden spoon in the middle of the tank of water for Daniel to focus his DSLR camera on. He used that time to make all of his settings selections, then the spoon was slowly pulled out of the water. I held the Tupperware dish with the two paints in it barely above the water, only about an inch above the surface. Through trial and error, we found that an immediate cloud would appear if the paint was poured from a higher height, mostly due to a larger impact force and velocity. The paint was poured, and the interaction between the paint and water did the rest of the work. An image depicting this set-up is shown in Figure 2 below.

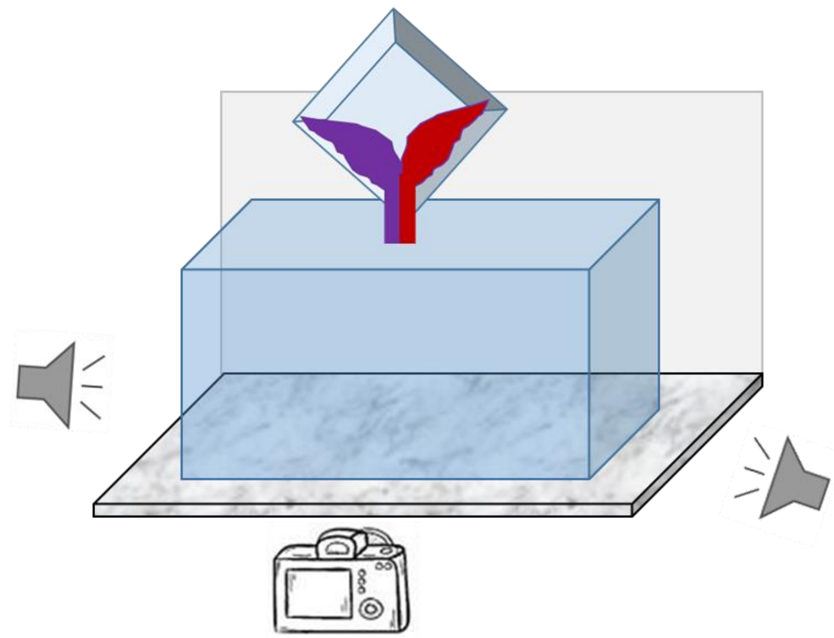

Figure 2: Test Set-up with Fish Tank on Counter Top, Poster Board Backdrop, Two Headlamps for a Light Source, and the Camera Orientation

In order for this flow visualization to occur, two main physical phenomena must be at play. First, viscosity is the internal friction in a fluid at the molecular level due to inelastic collisions. A fluid with high viscosity is thick like dish soap or honey. Meanwhile a fluid with low viscosity is thinner and "runny," like water out of the tap or chicken broth. Paint can act like both, depending on the forces on the fluid. This is one of the things that makes paint so applicable. When in the can, paint is thick. But as soon as a brush is dipped in and spread on a wall or other surface, the paint will thin and cover the surface. These are the characteristics of a non-Newtonian fluid. In continuum mechanics, a Newtonian fluid is one in which the viscous stresses arising from its flow, at every point, are linearly proportional to the local strain rate. Strain rate is the rate of change of a fluid's deformation over time. The plot in Figure 3

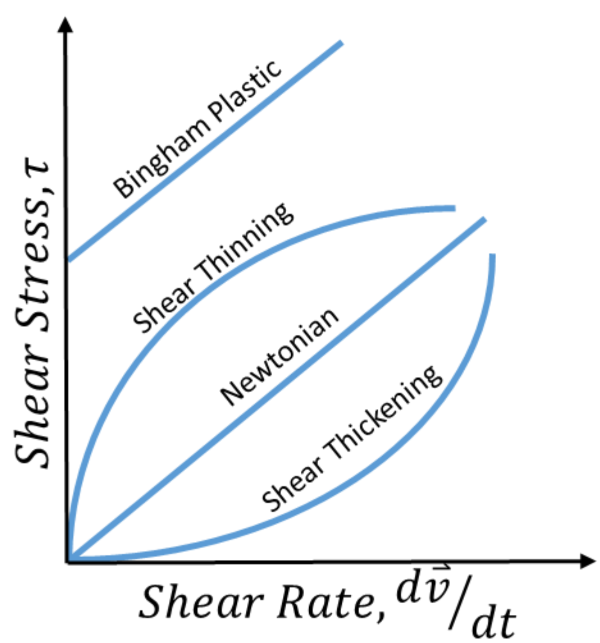

Figure 3: Shear Stress vs. Shear Strain of Newtonian and Non-Newtonian Fluids

shows the stress versus strain of common fluids.

According to Newton's Law of Friction, the paint shears under the gravitational forces, and begins to flow down in the fish tank. The shear stress from gravitational forces can be found using the following equation:

$$\tau = \mu \frac{d\vec{v}}{dy}$$

Where τ is the shear stress for a fluid with given viscosity μ, acted on causing the fluid to flow with velocity $\vec{v}$, giving the velocity gradient $d\vec{v}/dy$ as the shear rate. For many fluids (Newtonian fluids), the viscosity is constant resulting in the straight line for a slope. However, a non-Newtonian fluid has interaction between large particles resulting in the nonlinear relationship between shear rate and shear stress, as observed. Viscosity of a fluid is given by Power-law, or the Ostwald de Waele relationship, as:

$$\mu_{eff} = K\left(\frac{du}{dy}\right)^{n-1}$$

Where μ_{eff} is the effective viscosity for a Newtonian or non-Newtonian fluid as a function of K, the material constant for the fluid known as the flow consistency matrix. For Newtonian fluids, n=1 which forces the shear rate to go to 1, resulting in viscosity as a material property only. If a material is shear thinning, also known as a pseudoplastic, then n is less than 1. This results in the viscosity being a function of both the material property and the shear rate. In fact, assuming n = -1 for latex paint, the equation for shear stress becomes:

$$\tau = K\left(\frac{du}{dy}\right)^{-2}$$

Which matches the concave-down parabolic relationship shown in Figure 3. The other key to capturing these images was using non-water-based paint. Many paints are water-based, which would make the paint dissolve in the water quicker, similar to what saw when pouring the paint from higher heights. Using non-water-based paint ensures that the dye molecules go wherever the paint flows more orderly. This is what creates the fantastic ribbon flowing in Figure 1, where the different colored latex paints sink down the fish tank together but do not have enough time to disperse or mix with the water.

As for the twisting and turning of the ribbon as it fell through the water, the most likely cause is a negatively buoyant plume suddenly started at the top of the water tank. The leading edge of the paint ribbon appeared to hold its shape as it was falling, but the shear thinning of the paint made it separate on the tip fist. The rest of the ribbon reacted to slight vortex rings developing in the water as the paint fell to the bottom, but did not separate immediately.

Visualization and Photography Techniques

The visualization technique was a simple one, utilizing common materials in the kitchen to capture the colorful paints flowing down a fish tank. As for the shot itself, the photograph was taken with a Canon EOS 7D digital camera. The camera was held about even with the main detail of the flow, and a foot in front of the flat face of the tank to capture the image shown. The camera was zoomed in slightly, then the boundaries cropped out in Photoshop. The aperture was set to a larger f-number of f/9 to allow more light to enter the camera since the sources of light were not bright compared to natural sunlight. The shutter speed was set to 1/500 sec to try to eliminate as much motion blur as possible while the paint was moving very quickly. We had a tripod for capturing images, and this one was taken using the tripod. And lastly, the sensitivity was set to a pretty high ISO of 1600. The high sensitivity resulted in the addition of noise (as seen in the paint ribbon of Figure 4 below, which is the original).

Figure 4: Original Image

Once the picture was taken, it was edited in Photoshop. As previously mentioned, the borders were cropped to center the ribbon fluid flow while limiting the distractions in the image. The color contrast was then edited using the curve adjustment tool. Each end of the RGB color spectrum, the whites and the blacks, were brought in to fully utilize the entire range of contrasts. I used the magic wand tool to highlight and basically delete the distractions in the background by making it black-and-white. The shadow to the back right of the ribbon and the smudges on the lower left of the original image, again shown in Figure 4, were removed using clone stamp. Last, the sharpen tool was used to highlight the edges of the ribbon just slightly. The original image snapped by the camera on the evening of November 28th, 2016, is shown in

Figure 4. All of these edits result in the final image, again shown in Figure 1 on the first page and behind the title page.

Conclusion

In the end, the image reveals the true visual beauty of the interaction of different materials with varying densities and viscosities. It was also a perfect final team assignment as we all had the chance to have fun and get messy playing with paint then capture fantastic images the same night. The inspiration for this image came from Daniel's idea to capture images similar to Professor Truscott and fellow student Harrison Lien. Although the design and set-up were fairly simple, the image ended up harder than I imagined to capture and make it look the way it does. I like the fact that this image has great contrast between the gray-scale background and the bright highlights in the ribbon of latex paint. I also like the fact that the path of the ribbon is fairly simple, but a couple twists and turns shake up the simplicity. Overall, the intent of this image was fulfilled via some enhancements during many hours of post-processing.

References

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