Team First 2016

Magnetorheological fluid mixing

Alex Rosenberry

Teammates: Preston Marcoux, Katie Yarnell, Branden Goldenberg

Introduction

Flow visualization is a fun and creative way of exploring interesting or dramatic fluid flows and behaviors. For this assignment, we teamed up to capture the most interesting flow phenomenon we could. The goal of our team was to work together to each capture an interesting flow phenomenon, helping each other create our own images. Our team wanted to capture some of the most interesting behaviors of ferrofluid. Instead of creating our own flow apparatus, we used an existing flow visualization setup provided by the Integrated Teaching and Learning Laboratory. Because the setup was not ideal for photography, we did not capture all the behaviors of ferrofluid that we set out to, but instead captured some different behaviors of ferrofluid that are not always seen. The image that I captured is of ferrofluid falling through a colored alcohol solution after being agitated with a magnet. Instead of showing the ferrofluid being actively manipulated by a magnet, this image instead reveals the behavior of the fluid as it reshapes itself and flows after being affected by the magnet. As will be explained later, the fluid we examined turned out not to be a real ferrofluid, but instead something known as an MR fluid.

Flow Apparatus

The flow apparatus here is a jar of 30% isopropyl alcohol, with 70% water, and light food coloring. In the jar is also about half an ounce of ferrofluid, which in this case is mineral oil with microscopic iron particles in it. This ferrofluid was not of the highest grade, and while typical ferrofluid has iron particles in the nano-scale, these particles are not nearly so fine. This becomes evident when applying a magnetic field to the fluid, high grade ferrofluid makes very aggressive spikes and clearly defined shapes, while this slightly lower grade fluid makes "softer" shapes and less defined spikes. This type of fluid is not technically "ferrofluid", but is instead known as a magnetorheological fluid(MR fluid). Magnetorheological fluids still change viscosity and behavior when subjected to a magnetic field, but do display different physics than true ferrofluids. Because the particles in MR fluids are larger than in ferrofluids, the particles are too dense for Brownian motion to keep them suspended in the oil carrier, and will settle out with time.

Jars of MR fluid in solution 1

While the physics behind MR fluid behavior in a magnetic field are very interesting and unique, they are not on display in this image, so instead of discussing those physics I will instead discuss the mixing of immiscible fluids with differing densities. After agitating the MR fluid, the particles and the carrier fluid can be said to be totally mixed, and treated as one solution. In addition, the isopropyl and water solution is also totally mixed, so we can simplify this fluid system as having only two different immiscible fluids interacting. The MR fluid is both denser and more viscous than the alcohol-water solution. This causes the MR fluid to fall through the lighter solution. Really, the only force acting on this system is gravity. The viscosity difference is what causes the globules in the MR fluid to bunch together as it falls. In addition, the high viscosity makes the MR fluid resistant to shear stress, and this is what leads to the round shapes in the MR fluid, especially some of the perfectly round globules. One particularly interesting feature of this image is the long strung out line of MR fluid in the background. I found this to be quite striking, and a very cool visualization of how high and low viscosity fluids interact together.

Technique

The visualization of this phenomenon is aided by the dyed background solution, which was a light green/blue color. This provided a nice contrast to the pitch-black MR fluid. In order to really capture everything that was going on with the fluid, a lot of light was needed. The subject was small and dark, and all the light we could get was necessary to reveal the details of what was going on. The jar of fluid was placed on an overhead projector surface, which was lit from below, and was also placed in front of a projector, with the projector displaying white to shine light on the front of the fluid. In addition, a separate handheld halogen lamp was placed to the left of the jar to make the image as bright as possible. As it was, all of this light was still barely enough, as the raw image turned out fairly dark still.

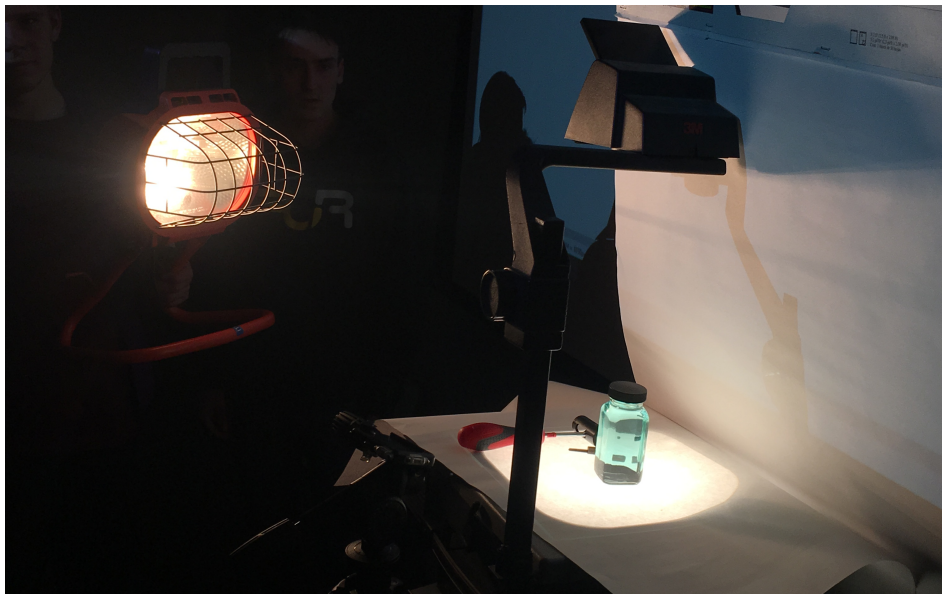
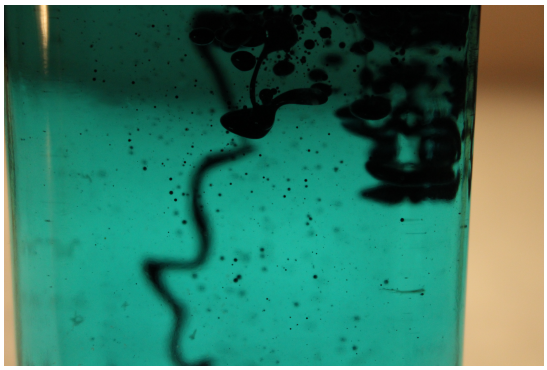


Image Setup 1

This image is very close up, and is about as small of a field of view that it was possible to take with this camera without using a macro lens or extender tube. From the right edge of the image to the left edge, the field of view is approximately 1.5 inches. The lens was placed about 1 inch from the glass jar, and closer to 1.75 inches from the in focus MR fluid. The 18-55mm Canon lens was zoomed all the way in to a focal length of 55mm. The image was captured on a Canon Rebel SL1 with an 18 megapixel crop sensor. The final edited image was cropped down to 3831 × 2586 pixels. Because of the low light, a high ISO of 1600 was used. Because I was capturing moving fluids, and needed a high time resolution, the highest speed shutter rate possible was used, at 1/4000th of a second. The aperture was opened to f5.6, which still provided a very shallow depth of field.

Most of the time spent working on this image was in post processing. As can be seen, the original image was extremely dark and lacked detail and a pleasant background. I used Photoshop to fix up the image, and used extensive use of the "dodge" tool. This brightened up the entire image enough to see detail in the fluid forms. I also used "unmask" and "sharpen edges" in Photoshop to try to remove some of the waviness caused by the imperfect glass jar I was shooting through. I also blended the darker upper background with the lighter lower background. Finally, the image was cropped down substantially to hide the distracting elements of the jar and the background. Shown below is the image pre-and post processing.



Conclusion

I am happy with how this image turned out. I was initially disappointed in the lack of quality shots of the MR fluid being manipulated by magnets, but was pleasantly surprised at how nice the image of the fluids mixing turned out. I think that we could explore this phenomenon much more if we used a larger volume of liquid. Our jars were very small, and the glass was very unclear, which limited the clarity of our images. I also wish that the image were brighter. We used all the available light we could find on a short notice, but it was still barely enough. A flash might have helped, but when we tried using a flash we got reflections off of the glass jar. I think in order to fully visualize this we would need a separate flash off to the side that could be triggered remotely, instead of using the built in camera flash.