Team Third | MCEN 4151 Flow Visualization

Dennis Can

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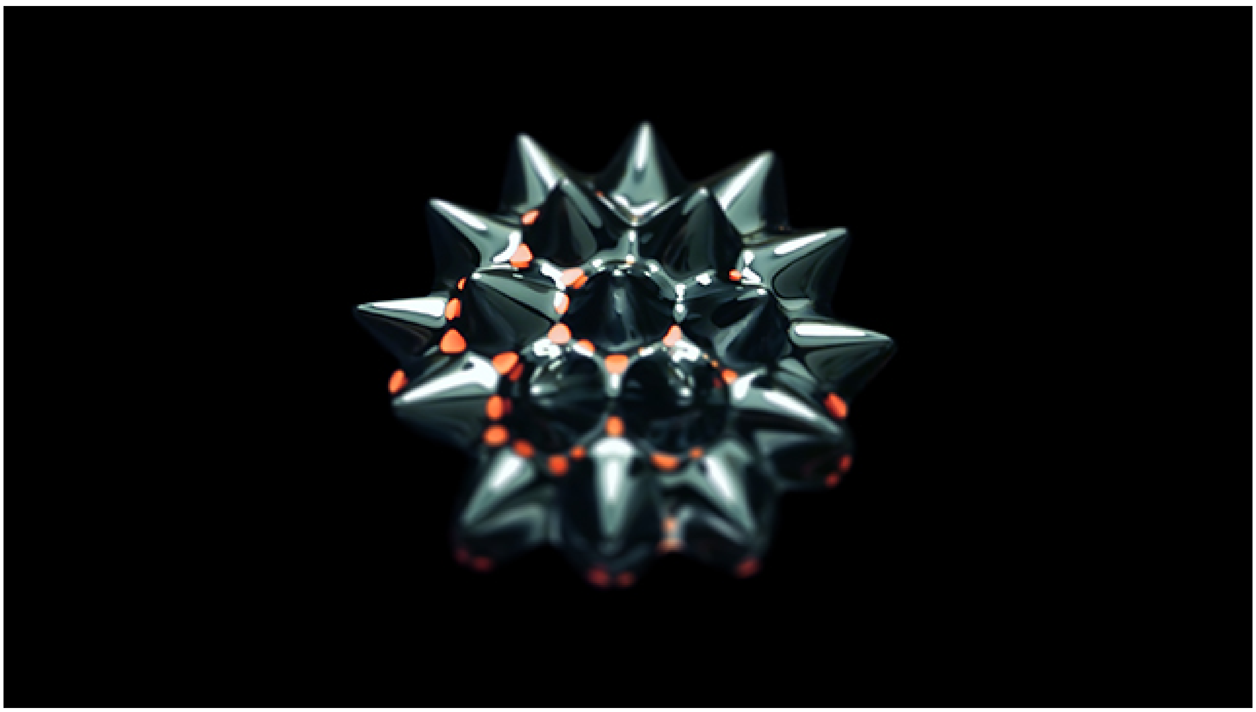


1 Introduction

The purpose of the Team Third assignment is to explore the interaction of acrylic paint with ferromagnetic fluid exposed to a magnet. The intent was to visualize the iconic spikes formed when exposing a ferromagnetic fluid to a magnet but also to add originality to the photo by combining another fluid.

2 Apparatus Setup

As shown in Figure 1, the light source is aimed downwards on top of the table, leaving only a 1 inch gap. The purpose of this setup is to remove reflections of the light bulb from the ferromagnetic fluid. Having the light set up this way also allows for one side of the ferromagnetic fluid to be illuminated while the other side remains black. This back-lit effect adds a better sense of drama. A clear cup is required to allow the light to pass through the cup while also being able to hold a small amount of ferromagnetic fluid. The particular cup used here is a disposable plastic cup with a 2 inch diameter base that was trimmed to a shorter height. The cup is positioned 1 inch away from the light source to enhance the intensity of the reflections. Several layers of newspaper are placed on top of the table for easy clean up. It is recommended to use at least 3/4 inches of newspaper since it will bleed through very easily if spilt on. A small magnet will also be required to create the fluid patterns. For the image captured in this report, the magnet was positioned directly under the cup. This was done to avoid having any ferromagnetic fluid stick to the magnet.

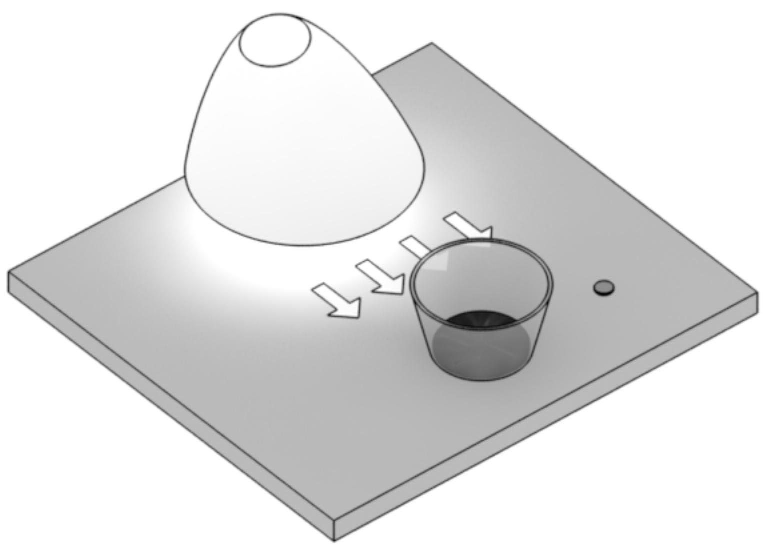


Figure 1: Apparatus setup showing the light source with a diffusive cover indirectly illuminating the cup of ferromagnetic fluid and a small magnet that will positioned under the cup

2.1 Handling & Disposal

When handling ferromagnetic fluid, it is recommended to cover any surfaces in the room that are susceptible to splashing. Also, the use of a single magnet is advised since having two magnets near each other could cause sudden attraction, which could cause the ferromagnetic fluid to splash everywhere. Use disposable gloves to avoid staining your hands, and wear safety glasses to protect your eyes. As mentioned earlier, using at least 3/4 inches of newspaper is recommended for easy clean up. Use a pipette or straw to transfer the ferromagnetic fluid to the cup, and ensure that the container containing the ferromagnetic fluid is properly sealed in case it is accidentally knocked over.

The ferromagnetic fluid is non-toxic, but it will easily stain objects. When disposing ferromagnetic fluid, do not pour down the drain. Instead, soak up the ferromagnetic fluid with a paper towel and dispose in the garbage along with the plastic cup. Since the amount of fluid required for the photograph is small, a single sheet of paper towel can soak it up easily. In the case that a lot of ferromagnetic fluid is used, dispose the liquid by taking it your nearest oil recycling service. Another option is to pour the ferromagnetic fluid back into its original container.

3 Fluid Dynamics

The fluid dynamics of the ferromagnetic fluid captured in this photograph can be explained by normal field instability, and the ability for the acrylic paint to stick to the ferromagnetic fluid is accomplished by adhesion.

Normal-Field Instability The ferromagnetic fluid itself is comprised of nanoscale iron particles in a pool of surfactant and a carrier fluid, which can be oil or water based. The surfactant is added to prevent clumping of the iron, or magnetite, and is accomplished by lowering the surface tension between the carrier fluid and magnetite [1]. The carrier fluid makes up most of the composition, and the particles are suspended uniformly by Brownian motion, which is the random motion of particles suspended in a fluid. The Brownian motion prevents the magnetite particles from settling due to gravity. When exposed to a magnetic field, peaks and valleys form the spikes of the ferromagnetic fluid. These peaks and valleys are due to normal field instability, where the force of the magnetic field destabilizes the interface, held together by gravity and surface tension. According to Tsori in *Polymers, Liquids and Colloids in Electric Fields: Interfacial Instabilities*, "normally oriented magnetization transforms the flat surface of a pool of the ferrofluid into a lower energy surface having an array of peaks that are spaced apart from each other" [2]. The distribution of the magnetic field is shown in Figure 2. Tsori claims that the increase in the difference in normal stress across the interface is responsible for the formation of the peaks.

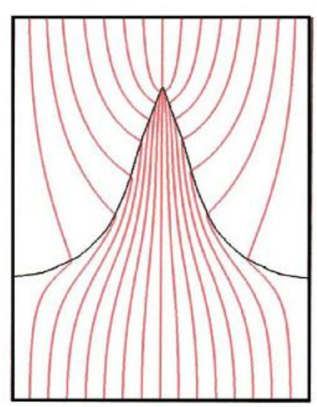


Figure 2: Distribution of magnetic field

Adhesion The acrylic paint attaches to the ferromagnetic fluid via adhesion, where there is attraction between two unlike molecules [3]. Since the ferromagnetic fluid contains a carrier fluid that is oil based—and the acrylic paint being water based— mixing does not occur because oil is a hydrophobic molecule. If the acrylic paint is not disturbed, the adhesion force is sufficient to remain on the surface of the ferromagnetic fluid.

4 Visualization Technique

The visualization of the ferromagnetic fluid requires the ferromagnetic fluid itself, acrylic paint in a dropper bottle commonly found at a hobby store, one 1/4" x 1/16" Neodymium disc, and a plastic cup. To prepare the setup, cut the plastic cup to a reasonable height where the fluid can be contained without spilling over the edges. Also, be sure to place the recommended 3/4 inch thick newspaper below the cup for easy clean up. Add 1 tablespoon of ferromagnetic fluid inside the cup, and then place the Neodymium magnet underneath the cup or the newspaper. After the spikes of the ferromagnetic fluid are visualized, then carefully add 2 drops of the acrylic paint near the surface of the ferromagnetic fluid. If the drops are placed too quickly or placed from a great height, the acrylic paint will tend to slide off and not adhere to the ferromagnetic fluid. When placing the drops, the height of the dropper was less than 1 cm from the ferromagnetic fluid. If dropped correctly, the acrylic paint will form small circles between the spikes of the ferromagnetic fluid.

The lighting of the scene requires only a single light source that is positioned near the surface of the table as shown earlier in the apparatus setup. The reasoning for this position was to create a dramatic back-lit effect on the ferromagnetic fluid, where one side is illuminated and the other side is dark. This effect also adds clarity to the shape of the spikes and removes unwanted reflections by the light bulb. No flash is required.

5 Photographic Technique

The specifications for the photograph are shown below. Since I did not have a macro lens, a Samsung Galaxy S5 was used to photograph the details of the fluid instead. The aperture and focal length are fixed to f/2.2 and 31 mm, respectively [4]. The ISO was the only variable option and was set to 100 since the lighting was sufficient to reveal the fluid details.

Table 1: Image Specifications

Camera	Samsung Galaxy S5
Aperture	f/2.2
Shutter Speed	N/A
ISO	100
Focal Length	31 mm
RAW Image Dimension	3984x2984
Final Image Dimension	2861x1609

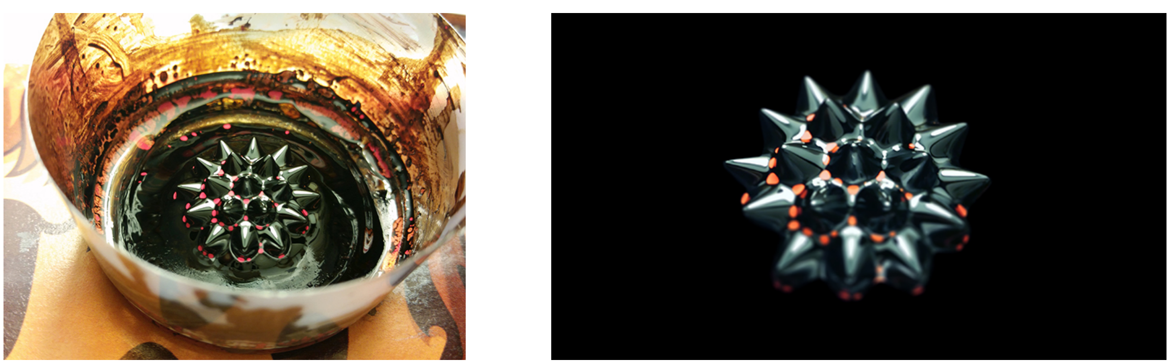
5.1 Field of View and Distance from Object to Lens

The approximate distance from the camera to the subject was 2 inches. Given that the cup is 2 inches in diameter at the base, the size of the ferrofluid is approximated to be 0.92 inches in diameter, and the acrylic spots are approximately 0.05 inches in diameter.

5.2 Post-Processing

The post-processing involves several quick steps, including background removal, color correcting, lens blurring, and cropping. The software used is Photoshop CC 2015. The background is first removed by blacking out the large areas and leaving the subject untouched. Then, using a brush with 65% hardness, the remaining background is carefully removed around the edges of the subject. The hardness of the brush controls how sharp the edges will appear in contrast to the black. Using 65% hardness provides a good mix of softness and hardness so that the image appears as if it were the original photograph. The edges are further refined with a smaller brush size with a higher hardness of 80% to give the edges sharpness. Now that the background is removed and the subject's edges are cleaned up, the image is color corrected to move the midtones and highlights to a more blue color. The sunset red spots are selected and color corrected to move the midtones and shadows to be more yellow. As a result, the contrast between the cool blue and hot orange provides a sense of drama.

Since the object is small in scale, having a shallow depth of field would enhance the visuals. The original photograph does not have a shallow depth of field as I would have liked; instead, I used the lens blur feature to add artifical depth of field. This is done by first creating another layer in the channels tab containing the red, green and blue channels. This new layer represents a map of where we want the image to be blurry and where we want the image to be clear. I used a simple black-white-black gradient map, where the white region represents the area in focus. Once the layer is complete, use Photoshop's Lens Blur feature and select the gradient map layer as your source. From there, I adjusted how intense the lens blur would be and applied the filter. Finally, the image is cropped using 16:9 aspect ratio. Figure 3 shows the results of the aforementioned post-processing.



(a) Original photograph

(b) Edited photograph

Figure 3: Post-processing results

6 Conclusion

The image reveals the interaction between a small Neodymium magnet and ferromagnetic fluid and acrylic paint. I enjoy the small acrylic spots and the black background which provides a sense of mystery, drama, and science fiction. Since the interaction of the fluids is simple, the physics are well understood. I fulfilled my intent to produce an original photo while also keeping it simple but interesting. I would have liked to use a dedicated macro lens to produce a higher quality image.

References

[1] C. Williams, "Ferrofluid: A Brief Overview." [Online]. Available: http://www.microscopy-uk.org.uk/mag/artdec13macro/Williams_Ferrofluid.pdf [Accessed 11 December 2015].

[2] Y. Tsori, *Polymers, Liquids and Colloids in Electric Fields: Interfacial Instabilities.* World Scientific, 2009.

[3] Hyperphysics, "Cohesion and Adhesion." [Online]. Available: http://hyperphysics.phy-astr.gsu.edu/hbase/surten.html [Accessed 11 December 2015].

[4] L. Rehm, "Samsung Galaxy S5 camera review," July 2014. [Online]. Available: http://connect.dpreview.com/post/6973057172/samsung-galaxy-s5-camera-review [Accessed 27 November 2015].