Image/Visual 4, Ferrofluid

Author/Photographer: **Ryan Wells**
Collaborators: **Kelsie Kerr, Maridith Stading, Will Dietz**
Assignment: **Image/Visual 4**
Course: **MCEN 5151, Flow Visualization**
Date: **November 16, 2022**

Figure 1, Depiction of the Flow Phenomenon of Ferrofluid in a clear dish under the effect of a magnetic field

Introduction

The image above in Figure 1, was taken for the fourth Image/Visual project in the MCEN 5151, Flow Visualization course at the University of Colorado, Boulder in the Fall 2022 semester. The purpose of Flow Visualization is to capture and observe fluid phenomena while exploring the interface between art and science [2]. The image in Figure 1 depicts the phenomenon that occurs when ferrofluid, a suspension of magnetic nanoparticles, is brought into a magnetic field [3]. When a magnet is brought close enough to ferrofluid it acts on it causing the fluid to attract towards the magnet. In Figure 1, the magnet was held under a collection of ferrofluid causing spikes. The spikes in the main subject of the image occur due to the surface instabilities from suspended and non-uniform particles in the fluid [1]. A strong enough magnetic field, about 10 mT, is required to create this effect of spikes and any ferrofluid outside of the magnetic field appears to act as a normal fluid [3]. The appearance of “cracks” and “folds” in Figure 1 were a side effect of the Saran Wrap that was covering the clear dish for cleanliness purposes. The orange color in the fluid outside of the main abundance of spikes is due to the iron oxide present in the ferrofluid used for the experiment. This experiment was conducted in collaboration with Will Dietz, Maridith Stading, and Kelsie Kerr using a bar magnet, ferrofluid, and a clear dish.

Fluid Physics

Ferrofluid is a very unique fluid because of its magnetic properties. Due to its properties, there are many applications for ferrofluid including but not limited to loud speaker cooling, sealing rotary shafts, and potential cancer treatment [3]. Magnetism is the main quality of ferrofluid and is the focus when discussing the physics behind ferrofluid. The magnetic field around the fluid is what caused the effect depicted in Figure 1. An example of this is shown in Figure 2 below, and an estimation of what the magnetic field looked like in the experiment is shown in Figure 3.

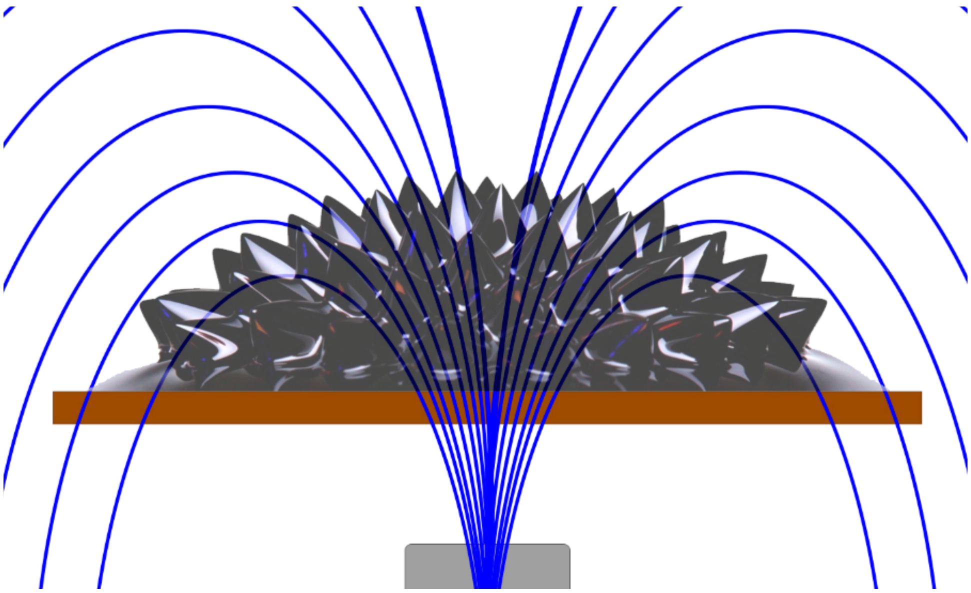

Figure 2, Depiction of how a magnetic field affects ferrofluid when placed below the fluid, from Reference [4]

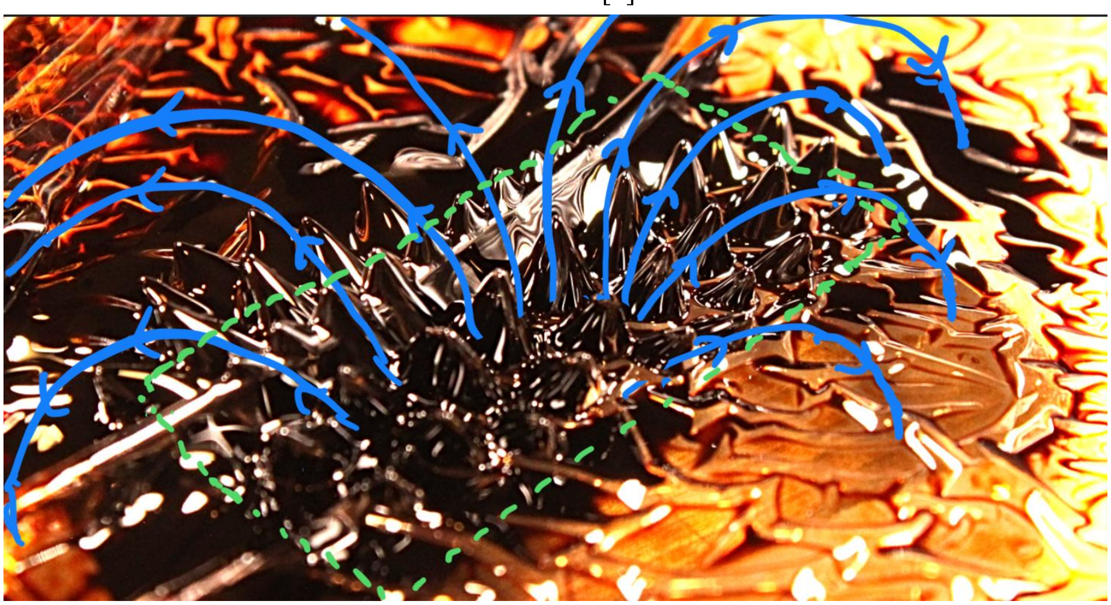

Figure 3, Depiction of the magnetic field lines (blue) and magnet placement (green) in the experiment depicted in Figure 1

As shown in both Figure 2 and 3, the spikes of the ferrofluid seem to follow the lines in a magnetic field. This highlights the instability of the surface particles in ferrofluid as they will follow the strongest forces of magnetism causing peaks and spikes. The size of the spikes is directly correlated with the strength of the magnetic field [1]. Given this, it is shown in the image that the magnetic field is strongest towards the center of the magnet, where the spikes are largest, and towards the edges the spikes get smaller. The spikes on the outer edges of the magnet also seem to point at a greater angle than the ones towards the middle providing a great depiction of the magnetic field. Another property affecting the spikes is the liquid content in the ferrofluid on the sharpness of the spikes. The less liquid (water, oil, or other liquid used in making ferrofluid) present in the ferrofluid, the sharper the spikes will be [1]. With this relationship, the image shows that in the experiment the ferrofluid had a high liquid content as the spikes are quite rounded and dull. This was also shown by the amount of liquid present in the clear dish (the orange colored liquid) while the ferrofluid was being moved.

Visualization Technique

The visualization techniques used in this experiment to take the photograph in Figure 1 were quite replicable and usual. This photo was taken indoors on a clear, glass dish covered in Saran Wrap with a white bed sheet under the dish. There were 3 IFB576 LED Lights with stands set at 4000K temperature and 100% power used with 2 in front at 45 degree angles and one directly behind the camera. The ferrofluid was poured into the dish, then magnets were placed underneath the dish in an attempt to experiment with the fluid. Then a magnet was placed in the ferrofluid which created some very different and unique effects. It was when this magnet was moved the Saran Wrap began to fold and wrinkle. Finally, a magnet was placed directly under a pool of ferrofluid causing the spike effect depicted in Figure 1. The ceramic magnet had a length and width of 3 inches by 1.5 inches and a height of 0.5 inches. The largest face of the magnet was placed against the glass dish directly below the puddle of ferrofluid in order to achieve the largest spikes.

Figure 4, the original photo of the photo in Figure 1 (pre-editing)

Photographic Technique

The image was taken with many different photographic techniques that complimented the experiment well. The distance from the center of the spikes to the lens was about 5 inches with a field of view of about 6 inches. The lens used was a Canon zoom lens with a 18-55mm focal length, 1:3.5-5.6 aperture and a thread diameter of 58mm. The digital camera used with this lens was a Canon EOS Rebel T1i. For the image taken in Figure 1 and 4, the aperture was f/10.0, the exposure is 1/80, a focal length of 55mm, and a 1600 ISO. The original image had a pixel size of 4752px width by 3168px height. This was then cropped down to 3176px width by 1679px height to bring focus to the collection of spikes in the ferrofluid. The post-processing of the image was very important to capture the true magnificence of the ferrofluid spikes. First, the RGB curve was adjusted to form an S-shape for the best color as well as a slight increase in exposure for brightness purposes. Then the contrast was increased along with the sharpness to capture the lines of light in the spikes in the fluid. The sharpness increase was the most effective adjustment as it defined the wrinkles in the Saran Wrap, the points of the spikes, and the lines of light reflecting in the fluid. While the wrinkles and folds in the image seemed like imperfections, they were kept in for a more exciting and intriguing look to the photo. Also, the overexposure in the top right seemed to be an issue at first, but upon review and peer comments it was found to provide another level of interest and color to the photo causing an almost “comic book” effect. The image came together as a whole with all of the details to create an eye-catching experience and dive into ferrofluid as a unique fluid.

Image Conclusions

The image taken in this experiment in Figure 1 captured an interesting and unique fluid that is uncommon to most people. Using a controlled environment and capturing intriguing images of ferrofluid can spread its beauty to more people. In the future, it would be a better experiment to explore the effects of more magnets in the same region along with different kinds of ferrofluid with lower or higher liquid contents. From an artistic standpoint, experimenting with different color lighting could amplify the beauty of ferrofluid even more. This experiment showed the beauty of ferrofluid and how one can be absorbed in curiosity by this unique fluid. Hopefully, it will open a viewer's eyes to more fluid phenomena in the world.

References

[1] Berger, Patricia, et al. “Preparation and Properties of an Aqueous Ferrofluid.” *ACS Publications*, American Chemical Society, July 1999, https://pubs.acs.org/doi/10.1021/ed076p943.

[2] Hertzberg, Jean. “SYLLABUS MCEN 4151/5151/ FILM 4200/ ARTF 5200/ ATLS 4151/5151 Flow Visualization: The Physics and Art of Fluid Flow Fall 2022.” *FLOW VISUALIZATION A Course in the Physics and Art of Fluid Flow*, 18 Aug. 2022, https://www.flowvis.org/wp-content/uploads/2022/08/syllabusF22.pdf.

[3] Odenbach, Stefan. “Ferrofluids.” *Journal of Physics. Condensed Matter*, Institute of Physics, Bristol, 1989.

[4] “Smart Materials : Ferrofluids & Magnetic Levitation.” *PhysicsOpenLab*, 3 Apr. 2017, https://physicsopenlab.org/2017/04/03/smart-materials-ferrofluids-magnetic-levitation/.