Flow Visualization: Team Third Report

MCEN 5151: Flow Visualization

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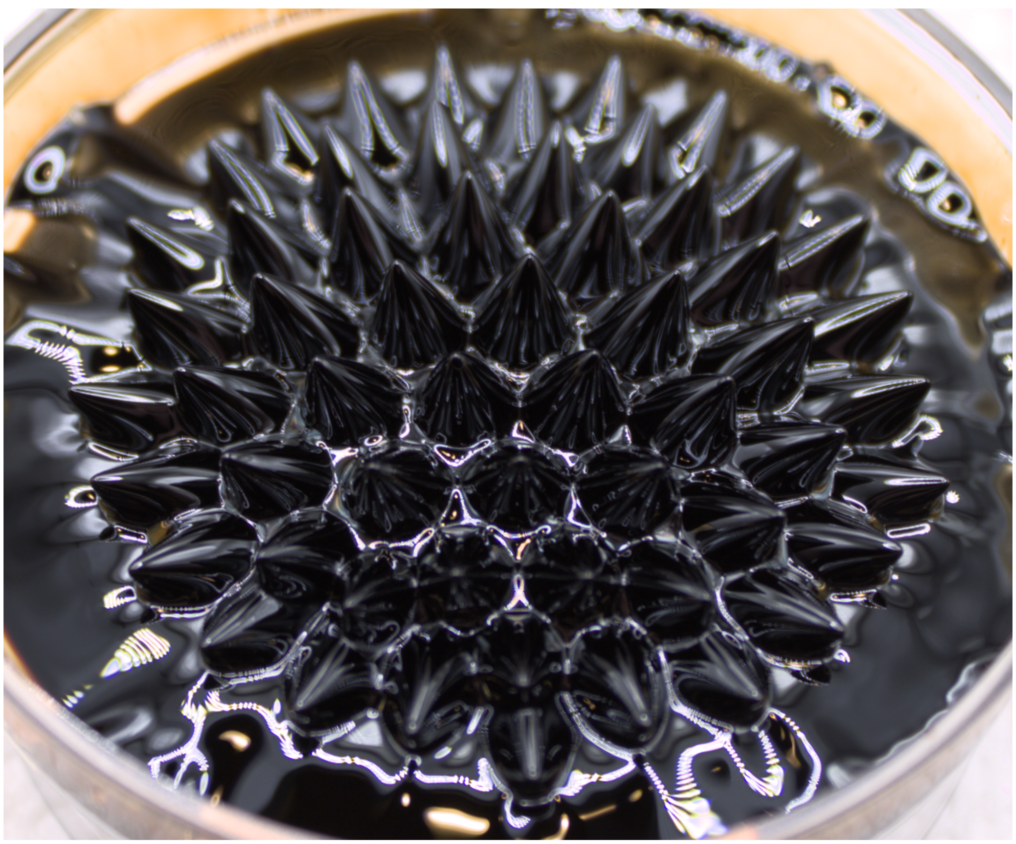

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I Introduction and Background

Visualization of fluid flow plays a pivotal role in the field of fluid dynamics, offering invaluable insights into the characteristics and dynamics of fluid motion. Additionally, a considerable portion of these experiments can be carried out using easily accessible and cost-friendly materials, producing captivating visual representations that illustrate the underlying physics. With this in mind, the overall purpose of this experiment was to collaborate with a team to capture the fluid phenomenon of our choice. As Team Purslane, we decided to capture the effects of a magnet on ferrofluid. This would allow us to better visualize the magnet field the ferrofluid follows and in turn, gain an understanding of the normal field instability.

II Experimental Set-up

For the experimental setup, I used a lightbox, Petri dish, ferrofluid, Cannon EOS Rebel T7 camera, and a fishing magnet (500 lb). Table 1 below showcases where I sourced each of these and their associated costs.

Equipment	Source	Cost
PULUZ Mini Photo Studio Light Box	Amazon	$20.99
Petri Dish	Amazon	$8.99 (10 Pack)
Ferrofluid	Professor Hertzberg Lab	Free
Fishing Magnet	Amazon	$15
Canon EOS T7 Rebel Camera	BestBuy	$479.99

Table 1: Equipment List

Figure (1) showcases a diagram of the experimental setup to better understand where everything was placed.

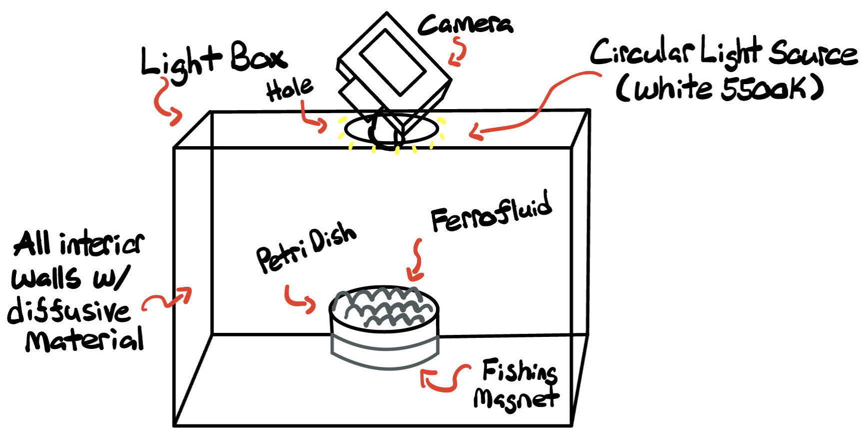


Figure 1: Diagram of the Experimental Setup

To begin, the lightbox was set up by unfolding it and plugging it into a power source for the lights. The lights were then set to the highest setting to ensure that the final image wouldn't be too dark and to capture as much detail as possible. The fishing magnet was then placed in the center of the lightbox with the magnetic surface facing upwards. A small amount of ferrofluid (About 2 tablespoons) was then poured into the Petri dish and allowed to settle for a few seconds to get rid of any bubbles. The Petri dish was then carefully placed on top of the magnet as the fluid would instantaneously react once it got close enough to a magnetic field. For this portion, the amount of spikes would be dependent on how close the fluid was to the magnet. The closer the fluid is, the more condensed the spikes are, and being too far would lead to minimal interaction. I chose to have about an inch of distance between the magnet and fluid which led to an even distribution of spikes across the dish. Once this was set up in the way I wanted, I took a picture from the hole on top of the lightbox to get a top-down view of the experiment. I then adjusted the distance between the magnet and fluid in varying amounts and repeatedly captured different images.

III Fluid Mechanics

Before we jump into the interesting phenomenon, let's take a closer look at the main player: the ferrofluid. This special fluid is made up of three key ingredients and is what allows this experiment to be possible. These key ingredients are: (Oehlsen, et al. 2022).:

1. A ferromagnetic compound (Iron Oxide Nanoparticles)
2. A surfactant that coats the magnetic compound to prevent agglomeration
3. A carrier liquid that suspends the magnetic compound

Essentially, the nanoparticles are so small that they stay suspended in the liquid and make it seem like it has strong magnetic properties. This means that you can control and move the liquid around using magnets. Another unique property is how the liquid will also form patterned peaks when exposed to this field. This same phenomenon that we were able to capture in this experiment is known as the *Rosenweig* instability, or the *normal field instability*. Essentially the instability forms when a fluid is subjected to a vertically oriented magnetic field. This increases the energy of the fluid which in response forms a spike to minimize its energy (Andelman and Rosensweig, 2009).

This patterning can only appear when the ferrofluid has a magnetization that exceeds a critical value known as M_C which is expressed in a dimensionless form as seen in Eq. 1 below (Andelman and Rosensweig, 2009).

$$\frac{\mu_0 {M_C}^2}{\sqrt{g\Delta\rho_m\sigma}} = 2(1+\frac{1}{r_p}) \tag{1}$$

Where:

1. μ_0 is the permeability of a vacuum.
2. g is the gravitational constant.
3. $\Delta\rho_m$ is the difference in mass densities of fluids across the interface.
4. σ is the interfacial tension
5. r_P is the dimensionless permeability ratio which is expressed as Eq. 2 below (Andelman and Rosensweig, 2009).

$$r_P = \sqrt{\frac{\mu_c\mu_t}{{\mu_o}^2}} \tag{2}$$

Areas within the fluid where this critical value is exceeded experience these peaks whereas other areas do not as seen in Figure (3a) in Section IV. Furthermore, the peak-to-peak distance can be described in Eq. (3) below (Andelman and Rosensweig, 2009).

$$\lambda = 2\pi\sqrt{\frac{\sigma}{g\Delta\rho_m}} \tag{3}$$

Figure (2) below showcases the distribution of a magnetic field and a potential peak through computational methods by Andelman and Rosensweig. It stands that the concentration of the magnetic field is closely tied to the formation of these peaks through an increase in the normal stress difference at the edges of these peaks (Andelman and Rosensweig, 2009).

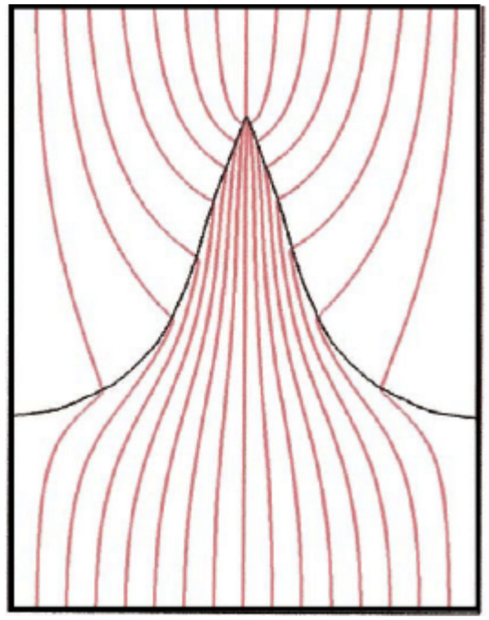
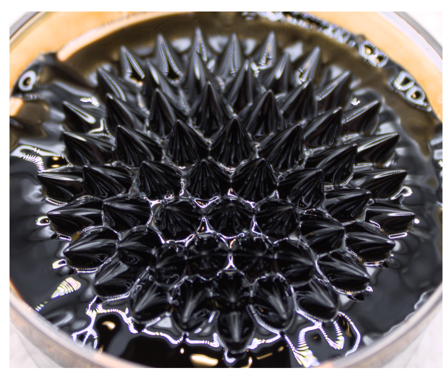


Figure 2: Finite Element Computation of Distribution of a Magnetic field and Cusped Shape of a Peak (Andelman and Rosensweig, 2009)

IV Visualization and Photographic Techniques

The photograph was captured within a lightbox with very diffuse material to spread the light out as much as possible. This made small details between each peak to be visible and provided a much richer contrast between the fluid and background. Figure (3a) showcases the final photo captured using this light source. However, during post-processing, I felt as if certain locations within the peak contained too much light so to alleviate this, the RGB curve was used to darken the overall image as seen in Figure (3b). Additionally, I also attempted to crop it such that the peaks would be the main focus, however, I could not find a way to circular crop it. As a result, portions of the Petri dish are still visible along with the background which I believe still takes away from the overall image.

(a) Original Photo



(b) Edited Photo

Figure 3: Original vs. Edited Photo

The final photo was captured on a Cannon EOS T7 Rebel which is a DSLR camera. The camera settings were set to ISO-1600, with an aperture of f/5.6, a focal length of 55 mm, and a shutter speed of $\frac{1}{20}$. The pixels of the final image were captured at 6000x4000 but sized down to 900x1300 in the cropped version.

V Conclusion

This image not only shows us how ferrofluids respond to a magnetic field but also sheds light on some fascinating behaviors. Specifically, it emphasizes how the magnetic field distribution influences the formation of distinct peaks. If I were to redo this experiment again, I would test different strength magnets to see how the patterns differ from one another. Additionally, I would attempt to add more vibrant colors to the ferrofluid in hopes that I could capture more visually striking patterns. This artistic touch not only makes the experiment visually appealing but could also offer a way to visually track the fluid's movement. One final touch I could've added is some motion to the entire experiment as this is a static image. I think it would make the experiment more interesting if I had a moving magnet below the Petri dish, allowing for a video of the dynamic changes in the ferrofluid pattern. However, all in all, a successful experiment in my eyes and thanks to my teammates Bradley Schumacher and Qisheng Lei.

VI References

[1] Andelman, D., & Rosensweig, R. E. (2009). The phenomenology of modulated phases: From magnetic solids and fluids to organic films and polymers. Series in Soft Condensed Matter, 1–56. https://doi.org/10.1142/9789814271691_0001

[2] Oehlsen, O., Cervantes-Ramírez, S. I., Cervantes-Avilés, P., & Medina-Velo, I. A. (2022). Approaches on ferrofluid synthesis and applications: Current status and future perspectives. ACS Omega, 7(4), 3134–3150. https://doi.org/10.1021/acsomega.1c05631