Ferrofluid and Watercolor

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Team First Assignment, MCEN 4151

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This video was intended to capture the effect of magnetic fields on ferrofluid, visualizing the normal field instability. Additionally, water-based pigment was added to the ferrofluid, demonstrating the interaction between the water and the oil due their differing polarities and adding color to the images to enhance the aesthetics. Ferrofluid, watercolors, and a container were obtained by Michael Sandoval, Cade Haley provided the location that the videos were filmed, and all members of the team assisted with the setup.

Ferrofluid consists of a suspension of tiny magnetic particles, usually iron, in a non-magnetic fluid, usually oil-based. The particles have an average size of 100 angstroms, or 1×10^{-8} m (Bérengère 2000). The setup used for this video was very simple: about 30 mL (one fluid ounce) of ferrofluid was placed in a 9 cm diameter petri dish. This dish was placed on a glass table and a rectangular permanent magnet was manipulated underneath the table to produce the normal field instability. In some shots, the dish was rested directly onto the magnet, which was sitting on top of the table. Syringes were used to deposit small amounts of watercolor into the ferrofluid. The image in Figure 1 shows the setup.

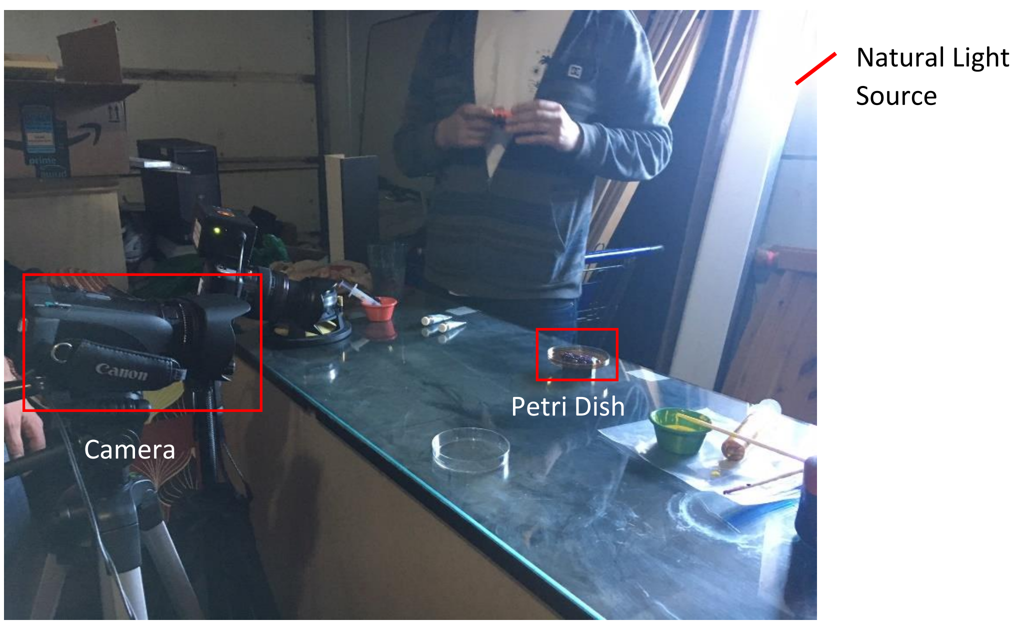

Figure 1. Basic Setup

The dominant behavior visible in the video is that of the normal field instability, which causes the ferrofluid to form spiked shapes when in close proximity to a strong magnetic field. When exposed to a magnetic field, the magnetic particles inside the fluid are motivated by magnetic forces to move and align themselves with the magnetic field. However, the forces of gravity and surface tension counteract the magnetic force and prevent the particles from moving until the magnetic field reaches a critical strength. This critical strength is determined by the following equation (Bérengère 2000):

$$H_{crit} = \left(\frac{2}{\mu_0} \frac{\left(\frac{\mu_0}{\mu} + 1\right)}{\left(\frac{\mu_0}{\mu} - 1\right)^2} \right)^{\frac{1}{2}} (\rho g \gamma)^{1/4}$$

In this case, μ_0 is the magnetic permeability of a vacuum, μ is the magnetic permeability of the ferrofluid, ρ is the density of the ferrofluid, γ is its surface tension, and g is the acceleration of gravity. Typical ferrofluid has an H_{crit} of about 10^4 A/m (amperes per meter). By comparison, the permanent magnet used has a magnetic field strength of approximately 0.2 Tesla, which is about 159540 A/m, much higher than the critical strength (Hadley 2017). This means that the magnetic force exerted on the particles, and thus the fluid, is larger than the weight of the fluid and its surface tension. This means that the particles tend to move along magnetic field lines normal to the surface of the magnet, in this case opposite of the direction of gravity. Gravity pulls the fluid back down between the field lines, creating the spikes that are seen in the video. The surface tension of the fluid ensures that the elevated regions do not separate from the rest of the fluid, and it limits their length.

The introduction of watercolors adds another layer of fluid physics to this situation. Because the water in the watercolors is polar (opposite ends of water molecules have different charges) and the oil-based carrier fluid of the ferrofluid is not, the water is repelled by the ferrofluid. This means that the watercolors do not mix with the ferrofluid and instead cluster in droplets on the surface, as the water’s surface tension means it tends to remain in one connected volume. Figure 2 shows what occurs when the ferrofluid is interacting with a magnet and the watercolors are deposited on top. The areas between the spikes create “troughs” where the watercolors collect. The watercolors flowing out through the gaps between the spikes create a phenomenon visible in one shot in the video where the watercolors appear to “shoot out” into the unperturbed fluid.

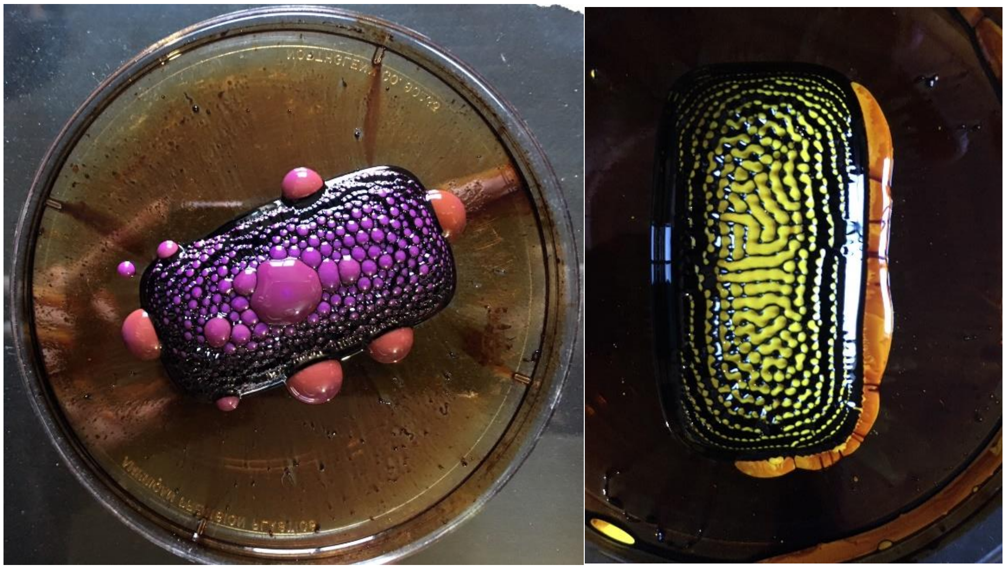

Figure 2. Watercolors Interacting with Ferrofluid

The normal field instability was able to be visualized with ferrofluid alone, as the protrusions were very visible without added fluids. The watercolors used were water-soluble professional colors that are packaged in tubes. About a gram of both purple and yellow watercolor was mixed with a quarter cup (60 mL) of water, and these mixtures were slowly added to the ferrofluid with syringes. The lighting used to achieve the shots was entirely natural and did not change between shots. There was a window five feet behind the table which provided all the necessary light and produced nice highlights on the ferrofluid as well as a reflection of the blue sky on the glass table.

The video was captured using a Canon Vixia HF G20 digital camcorder, shooting a 1920 x 1080 pixel image at 24 frames per second. The camera has a fixed lens with a variable 4.25-42.5 mm focal length and a maximum aperture of f/1.8. A variety of focal lengths was used to capture the various shots in the video, though the average was about 20 mm. The distance between the camera lens and the petri dish also varied between shots, but was never more than three feet (91.5 cm). The camera was kept close to the subject both to capture the detail of the flow and to take advantage of the reflection of the sky through the window in the glass table, which hid the magnet underneath and worked well aesthetically. The horizontal field of view ranged from 9 cm to about 1 ft (30 cm). The aperture, shutter speed, and ISO gain were f/2.8, 1/60 s, and 0 dB, respectively. These settings were chosen because they kept the detail of the flow visible while the reflection on the table appeared as an almost perfect mirror image of the window. The video was edited and post-processed using the Hitfilm 3 Pro software. The contrast of videos was increased slightly to make the difference between the colors more striking, and a “vibrance” effect was added that increased the intensity and sharpness of the highlights. No changes to the colors were made. A royalty-free music track, “ambient soundscape minivis,” retrieved from Pond5.com was included in the video.

The majority of the video presents the petri dish full of ferrofluid from a low angle so that the reflection in the table is visible and the fluid is dark with bright highlights, emphasizing its strangeness and the mysterious quality of its shape and movements. A strong emphasis was placed on the movement of the fluid and the resulting shapes, contributing to a dynamic and mysterious aesthetic, and the normal field instability is clearly visible. Unfortunately, the colors provided by the watercolor paint were not visible due to the lighting and angles used. I felt that the colors created a very striking aesthetic, and I wanted to show this in the video, so I included a high-angle shot that clearly showed the colors. However, due to the constraints of the tripod I was using the shot was handheld and thus not steady, and was also not fully in focus, so although the colors were beautiful the shot was not composed as I would have liked. Furthermore, showing the colors breaks with the dark, mysterious aesthetic present in the rest of the video. Overall, the video mostly achieves its intent, which is to portray the normal field instability of ferrofluid while evoking a mysterious mood.

References

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