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MCEN 5151
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Team 1 Report

Introduction

This project was the first team project of the flow visualization course that takes place at CU Boulder during the Spring Semester and is taught by Professor Jean Hertzberg. The purpose of this report is to describe how the phenomenon was visualized and captured by explaining the apparatus, physics, visualization technique and photographic technique used. For this assignment, my team (Jeremy Parsons, Jonathan Fritts, and Daniel Allen) and I decided to capture the gorgeous peaks and valleys that ferrofluids create when combined with a magnetic field (see apparatus section for more details). Since Jonathan was unavailable to meet for the photography of this project, he performed the majority of the physics research for this phenomenon. Daniel took a majority of the images. Jeremy and I alternated between dropping the ferrofluid and taking pictures with a second camera. For the image described in this report, I was taking the image, and Jeremy was dropping the ferrofluid. The final, edited image of the flow can be seen in figure 1, below, and in figure 6 within the Photographic Technique section of the report.

Figure 1 - Final, edited image of phenomenon

Apparatus

The flow apparatus was the same for all images captured. It consisted of a paper plate that was approximately 10 inches in diameter sitting on top of an empty fish bowl. The fish bowl was placed on white paper to help with the lighting for the experiment and with the cleanup required afterwards. On the underside of the plate (inside the fishbowl) was a rectangular 1” x 2” (approximately) magnet. On the topside of the plate—above the magnet so that the plate was sandwiched in between the magnet and object—the magnetic objects were positioned. The ferrofluid was dropped from a syringe onto the magnetic object (in this case the nut). For this image, the camera was positioned on a tripod with the lens in-line with the center of the nut, and about 4 inches away. No additional lighting was used. The apparatus set-up can be seen in figure 2, below.

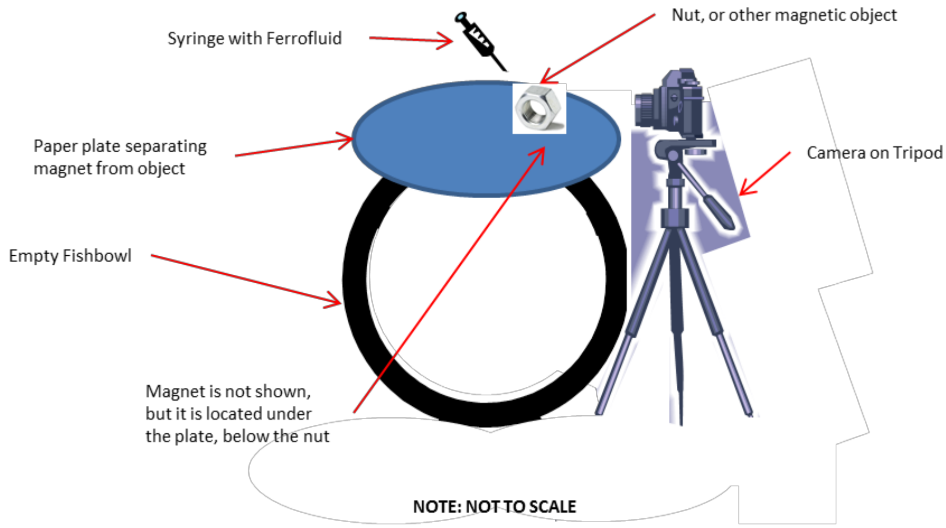

Figure 2 - Apparatus set-up

Physics

Note: the majority of the research of the physics was performed by Jonathan Fritts since he could not be present to perform the experiment.

Background

Ferrofluids were originally discovered at NASA in the 1960s when the researchers were attempting to develop methods that control liquids in space. The benefits were very clear—fluids could be controlled with a magnetic field and the strength of the field could be varied to better control the fluid and force it to flow as desired [1]. The ferrofluid substance has fluid properties of a liquid material and magnetic properties of a solid one. This is because the fluid contains particles of a magnetic solid that are approximately 10nm in diameter, and are suspended in a liquid medium. The array of spikes that are observed during the interaction of ferrofluids with magnets is the fluid standing up along the magnetic field lines [2]. A visual representation of this is seen in figure 3, below.

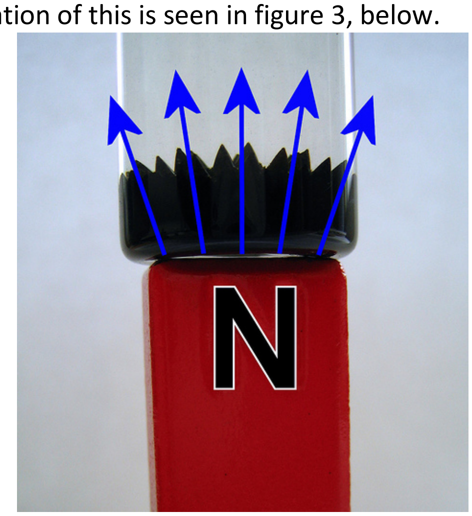

Figure 3 - Shows the north pole of a magnet repelling the ferrofluid (taken from [2])

Chemistry

Ferrofluids can be prepared by combining an Fe(II) salt and an Fe(III) salt in basic solution. This combination will cause the mixed valence oxide, Fe_3O_4 (magnetite—a small particle that most ferrofluids contain), to precipitate from solution [1]:

$$2\ FeCl_3 + FeCl_2 + 8\ NH_3 + 4H_2O \dashrightarrow Fe_3O_4 + 8\ NH_4Cl$$

In order for the ferrofluid to work and stay suspended in the liquid, the magnetite particle produced must remain small. This means that magnetic and Van der Waal reactions have to be overcome so that the particles don't accumulate. One way to prevent this from happening to keep the particles separated. This can be accomplished by adding a surfactant (such as cis-oleic acid) to the liquid which can generate either steric or electrostatic repulsions between the magnetic particles. This surfactant is a long chained hydrocarbon with a polar head that is attracted to the magnetic particle. The long chains of tails then act as a repellent cushion and prevent particles from approaching one another. Once water is removed from the formula, the preparation of the ferrofluid is complete [1]. This is further seen in a diagram of the outcome in figure 4, below.

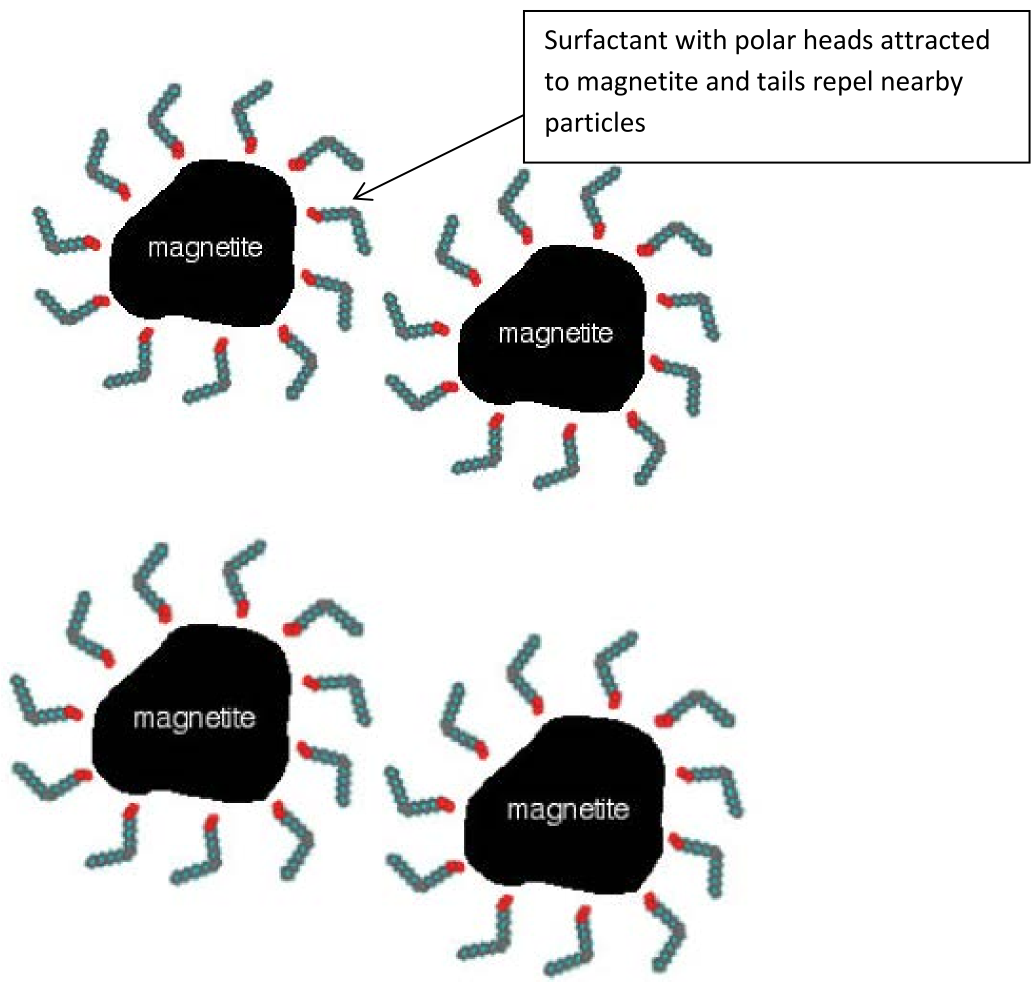

Figure 4 – Outcome of preparation of ferrofluid (adapted from [1])

Physics

When the ferrofluid layer is subjected to a uniform magnetic field, an interfacial instability occurs above a critical value of the magnetic field. This instability is called the "Normal-Field Instability", and gives rise to an array of hexagonal peaks [3]. The critical value for the magnetic field for the phenomenon is given by the equation below (taken from [3]):

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

Equation 1

In this equation, ρ is the fluid density, g is the acceleration of gravity, γ is the surface tension, μ_o is the permeability constant, and μ is the magnetic permeability. Additionally, the critical magnetic field is of the order 10^4 Am^{-1} [3]

Applications

Ferrofluids are used as liquid O-rings in rotating shaft seals where the fluid is held in place by permanent magnets and forms a tight seal. This is because it eliminates most of the friction produced from a traditional mechanical seal. Further, they can be used in x-ray generators and vacuum chambers for the semiconductor business. The seals are also used in computer disk drives to eliminate impurities such as harmful dust particles. Other applications include improving the performance of loud speakers by bathing electric coils in ferrofluid and dampening unwanted resonances to dissipate heat. There is current research involved in designing ferrofluids that apply magnetic fields to carry medications to specific areas of the body [1]. Other new applications include ferrofluid gauges, sensors and steppers [4].

Visualization Technique

The only fluid used for this visualization was ferrofluid which was obtained from a bottle in the ITLL. The amount of ferrofluid varied for each object and it was difficult to quantify the exact amount used. For this experiment, the ferrofluid was dropped onto the object from above, instead of using electromagnets which is more typical. No additional lighting was used, because when attempted, it resulted in the image looking washed out.

Photographic Technique

The camera used to capture this phenomenon was a Canon EOS Rebel T3 DSLR camera. The macro setting on the camera was used, with the default settings selected. For this image, the flash did not fire. The size of the field of view of the original, unedited image is approximately 6" tall by 7" wide. The lens was about 4" away from the nut and the macro mode on the camera was selected. The shutter speed, f-stop, aperture value, ISO speed, and focal length were 1/60 sec, f/4.5, f/4.6, 320, and 33.00mm, respectively. The original, unedited, image has pixel dimensions of 4272 pixels wide by 2848 pixels tall, while the final image has pixel dimensions of 1845 pixels wide by 834 pixels tall. Refer to figure 5 for the original image and figure 6 (or figure 1) for the final image.

Adobe Photoshop CS2 was used to edit the original image. The tools used were: crop, clone stamp, spot healing (in multiply mode) curves, and shadow/highlight. For shadow/highlight, the shadow bar was set to 0%, and the highlight bar was set to 50%. These modifications transformed the original image (figure 5) into the final image seen in figure 6.

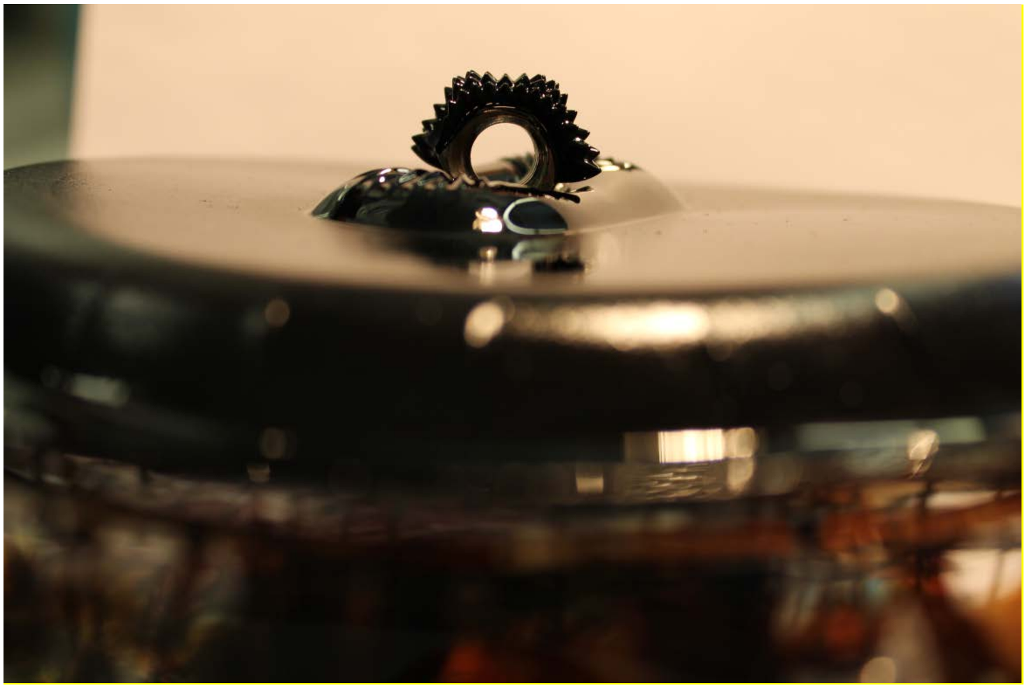

Figure 5 - Original, unedited image

Figure 6 - Final image

Conclusion

This Image does a good job of showing off the peaks and valleys that are observed with experimenting with ferrofluids. I like the depth of field that's present and how the blurriness in the foreground and background really brings out the sharpness of the ferrofluid formation. I think that the fluid physics are very well shown and defined in this image. My intent with taking and presenting this image was to show off ferrofluids in an amazing way and that intent was fully realized. To further develop this idea, a video of how the fluid gets dripped down and forms could have been shown. However, while there is always room for improvement, I am pleased with how this phenomenon was realized and shown.

References

[1] *A Materials Science Companion by A. B. Ellis, M. J. Geselbracht, B. J. Johnson, G. C. Lisensky, and W. R. Robinson. Copyright © 1993, American Chemical Society, Washington, DC*.

[2]"Ferrofluids." *Exploring the Nanoworld* (2008): n. pag. *National Science Foundation*. Web. 5 Mar. 2013. <http://education.mrsec.wisc.edu/background/ferrofluid/index.html>.

[3] Abou, Berengere. "J. Fluid Mech." *The Normal Field Instability in Ferrofluids* 416 (2000): 217-37. Web. 5 Mar. 2013. <http://pages.csam.montclair.edu/~yecko/ferro/oldpapers/DIRECTORY_Normal_Field_Instability/AbouWesfreidRoux_NormFieldInst.pdf>.

[4] Raj, K. "Advances in Ferrofluid Technology." *Journal of Magnetism and Magnetic Materials* 149.1-2 (1995): 174-80. Print.