Flow Visualization
First Team Image
Team 10

Maxfield Scrimgeour
With Jeremy Parsons and Peter Brunsgaard

Introduction

Ferrofluid is something that was originally designed by NASA to be used as a to be used in a weightless environment. Since the creation of ferrofluid it has been widely used in flow visualization phenomena from large corporations like Nike in commercials to individual users in their garage as a hobby. The use of ferrofluid provides a unique perspective into the magnetic field in which it is being surrounded by. A liquid that shows the details of the interaction with something that you cannot see provides a nice perspective into flow visualization, which is why it will be discussed here.

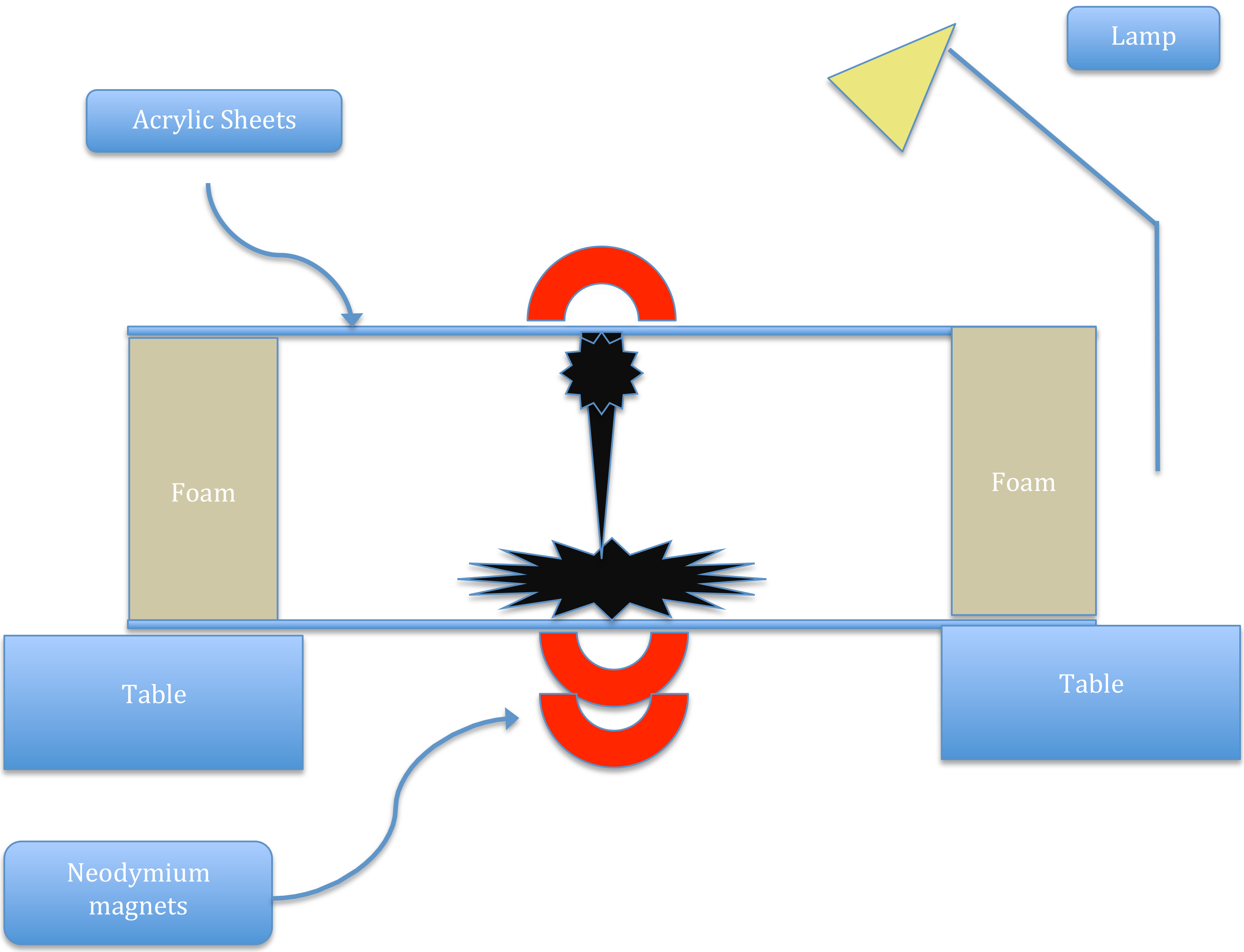


Figure 1: Diagram of set up

Apparatus

The above figure shows the set up of how the flow phenomena were captured. Figure 1 shows how there were two acrylic sheets separated by blocks of foam. These foam blocks were used as something that could compress with a constant pressure applied to them to draw the magnets on the top sheet closer to the ferrofluid on the bottom sheet. This allowed for a more control over the flow and a more stable scenario to avoid creating a large mess with the ferrofluid. The acrylic was suspended between two tables so the magnets below could be held directly onto the bottom of the acrylic sheet. When the foam was compressed it is possible to see the ferrofluid suspended in a magnetic field on both the top and bottom sheet of acrylic. The photo was taken with approximately 3 inches between each sheet at the time. Below the fluid at the bottom was a washer, which allowed the fluid an extra surface to elevate upon.

Physics

Ferrofluid is generally made with a combination of magnetite particles on the order of 10 nm and a surfactant. “Thermal motion of magnetite particles smaller than ~10 nm in diameter is sufficient to prevent agglomeration due to magnetic interactions” (Exploring the Nano World). The surfactant aids assures that the ferrofluid can remain a fluid and prevent agglomeration.

The phenomenon that happens when ferrofluid is brought close to magnets is known as the normal field instability. The mixture of magnetic and non-magnetic fluid destabilizes the interface when a magnet encounters a pool of ferrofluid. When the magnet is applied to this stability the denser materials are drawn to the bottom while the less dense materials float to the top of the spike shape that is seen within the fluid. In order for the hexagonal pattern of fluid to appear the magnetic field must cross the critical threshold. There is a second critical threshold at which point when this is passed the field turns from a hexagonal to square pattern (Abou, Westfreid, Roux). The threshold of the magnetic field is given by the equation below, which relates the density of ferrofluid, gravity, surface tension and magnetic permeability.

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

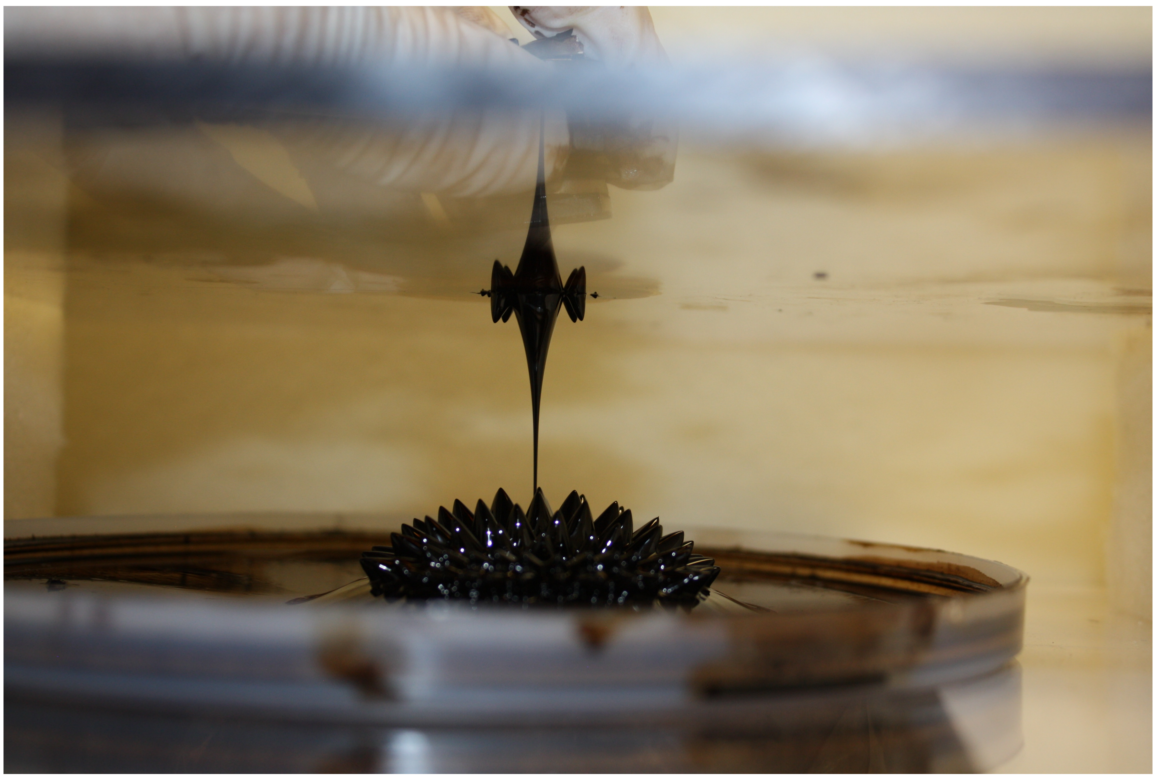
Figure 2

Photography

This image was taken using the apparatus shown above with early morning light coming through the window behind the fluid. The backdrop used for the photo was another large piece of foam, which had an almost white color to it. When taking the photo it was necessary for one team member to compress the foam apparatus while another was able to focus the camera and time the shot to capture the desired flow. An additional lamp was used off to the side with a towel over the bulb to help diffuse the light and reduce as many harsh reflections as possible. In addition to the lamp a flash was also used when capturing the image.

When capturing the image as many artistic elements were taken into consideration while capturing the image that led to the end image. Having a close proximity to the subject narrowed the field of view. The final distance was around 1 foot from the fluid, which helped eliminate many noisy distractions within the background and surrounding area. With this in mind the final size of the image before cropping is

about 1 foot by 6 inches. The acrylic in the top of the shot gives a distorted feel as if the image is being taken in a tunnel.
The image was captured with:
Camera: Canon EOS DIGITAL REBEL XS
Lens: Canon EF-S 18-55mm f/3.5-5.6 IS
ISO: 400
Shutter: 1/60
Aperture: f/4.5
Length: 36mm
This image was taken from its original state and turned black and white. From here the saturation and contrast were increased to highlight the flow. The image below shows the original photo.



Discussion

For this image the flow is shown very well. It is possible to see the ferrofluid creating the spiked peaks like it is so famous for. I like how you can really see the top fluid joining up with the bottom fluid very crisply. Something that I wish this photo had was a larger depth of field so that more of the ferrofluid was in focus and the hexagonal pattern was illustrated well. Something that bothers me is how the top flow doesn't line up with the bottom peak. This is due to the ring washer in the bottom as it is lined up with the field slightly behind the front peak that is in focus.

In order to take this further it would be interesting to see different objects inserted into the flow and to see how the fluid interacts with other liquids.

Conclusion

This shows work shows how the normal instability affects the ferrofluid and gives a visual representation of the magnetic field surrounding the flow. The overall shot does an excellent job highlighting the phenomenon occurring and provides a crisp view into the world of Nano particles and how they interact. The process of this experiment also revealed how much of a mess ferrofluid can make.

Sources

Abou, Bérengère, José-Eduardo Wesfreid, and Stéphane Roux. "The Normal Field Instability in Ferrofluids: Hexagon–square Transition Mechanism and Wavenumber Selection." *Journal of Fluid Mechanics* 416 (2000): 217-37. Cambridge University Press, 200. Web. 2016. <https://www.pmmh.espci.fr/~wesfreid/references/JFM416,217-2000.pdf>.

Boudovis, A.G., J.L. Puchalla, L.E. Scriven, and R.E. Rosenswieg. "Normal Field Instability and Patterns in Pools of Ferrofluid." *ScienceDirect*. University of Minnesota, n.d. Web. 4 Nov. 2016.

"Exploring the Nano World." *MRESC Education Grpu*. The Board of Regents of the University of Wisconsin System, 2008. Web. 4 Nov. 2016.