Black Magic

Ferrofluid Sculpture

Project 2: Group Phi

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Intent

I was first introduced to ferrofluids through this course, and I find them to be quite amazing. Their gravity-defying behavior when interacting with a magnetic field is beautiful and very interesting. In particular, I am very interested in the creation of ferrofluid sculptures by forcing the fluid to climb onto a metal object. The unpredictable behavior of the ferrofluid is a remarkable property, so I decided to create my own unique ferrofluid sculpture for this project. My intent was to capture an image that would spark curiosity and wonder in its observers.

Description of Apparatus

A small pool (~5 ml) of ferrofluid was placed in a clear Petri dish with a pipette. A 3/16" flat-top bolt was placed in the pool of ferrofluid with the threads pointed upward. To moderate the magnetic field strength, a 1/8" thick piece of plastic was placed under the dish. A ½" diameter neodymium magnet was placed directly beneath the metal bolt under the plastic spacer (Figure 1). With the bolt magnetized, additional ferrofluid was added to the tip of the bolt using the pipette. Next, a few drops of ferrofluid were placed on a second dish with a magnet placed beneath a second plastic spacer. The second dish was then held upsidedown and the small pool of magnetized ferrofluid was brought close to the bolt tip until the two ferrofluid sculptures joined in the middle. The original image in the Appendix also shows the full apparatus used to create this ferrofluid sculpture.

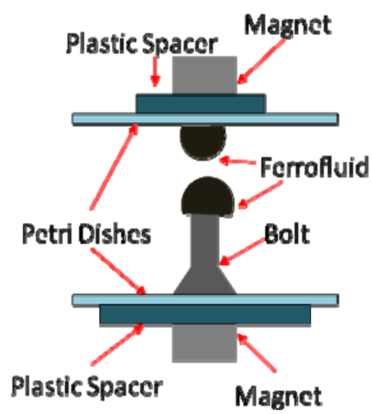

Figure 1: Diagram of sculpture setup

Fluid Flow Visualization with Ferrofluid

Ferrofluids are colloidal mixtures composed of three entities that give them their unique properties. The first key constituent of a ferrofluid is nanoscale particles of a ferromagnetic material (such as magnetite, hematite, or another compound containing iron). These small particles are responsible for the behavior of ferrofluid when subjected to an external magnetic field. The metallic nanoparticles are suspended in a carrier solvent, such as oil or water, which makes up the majority of the ferrofluid. The nanoparticles are coated with a surfactant, a fluid that lowers the surface tension of the surrounding carrier fluid [Chen et al, 2008 and Kodama, 2008]. The surfactant is a crucial component because it prevents agglomeration of the nanoparticles. Figure 2 shows how the different constituents of a ferrofluid interact.

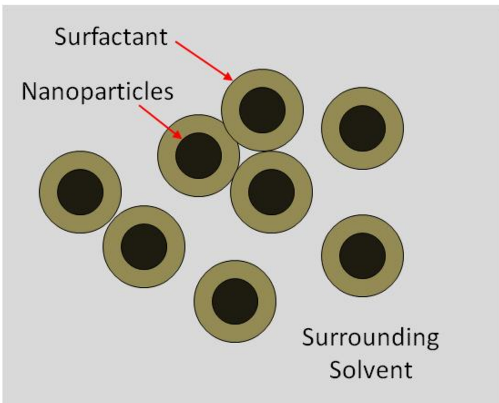

Figure 2: Small-scale diagram of ferrofluid and how its constituents interact

The ferrofluid used in this project was purchased on e-bay.com. The ferrofluid consists of hematite nanoparticles suspended in kerosene as the carrier solvent. The surfactant is oleic acid. The oleic acid molecules are not soluble in kerosene, but they will bind with the nanoparticles, making it the perfect surfactant to prevent agglomeration of the nanoparticles.

Photographic Techniques

All photographs were taken using an Olympus FE-370 8.0 megapixel digital camera. This camera has a focal length range of 6.3-31.5mm and an aperture range of 1:3.5-5.6. All photographs utilized the camera's "indoor" setting in conjunction with the "super macro" setting with the flash disabled. Table 1 lists detailed information about the final photograph.

Table 1: Details of photograph

Photograph Date	Mar 30, 2009
Field of View	0.75 x 1.25 inches
Distance from Lens Object	0.5 inches
Lens Focal Length	7.7mm
Original Image Size	3264 x 2448 pixels
Final Image Size	811 x 1030 pixels
Shutter Speed	1/80 sec
Aperture	f/4
ISO Setting	100

A white piece of cardboard was used as the background and the sculpture was lit from above with a desktop fluorescent tamp. The camera was placed flat on the desktop to keep it steady during photography.

Image processing was performed using the Paint.NET image editing software. First, the image was cropped so that the ferrofluid sculpture filled the field of view. Second, the contrast was increased using the "curves" feature. This brightened the background slightly, allowing more details of the sculpture shape to be apparent. Lastly, the sides of the bottom Petri dish were erased to clean up the appearance of the image and remove their distracting effect. The original image can be found in the Appendix.

Fluid Mechanics and Physics Demonstrated

Brief Overview of Magnetism

The neodymium permanent magnets produce a magnetic field, a type of vector force field. A vector force field has both a magnitude and a direction at every point in space. The direction of the magnetic field produced by a permanent bar magnet, such as the neodymium magnets used for this project, is depicted by Figure 3. The actual shape of the magnetic field for this project in unknown because the complex geometry of the metal bolt distorts the field slightly.

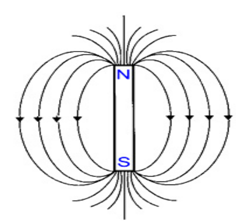

Figure 3: Magnetic field lines

The Rosensweig Instability

When the magnetic field strength applied to a ferrofluid reaches a critical value, the fluid surface suddenly transitions from an original flat surface to a circular pattern of liquid crests, which are the spikes observed in the image. This transition is known as the Rosensweig Instability [Knieling et al, 2007 and Chen et al, 2008]. The crests orient themselves along the magnetic field lines generated by the magnets. As demonstrated by this project, the critical magnetic field strength is small enough that the transition can be achieved with a common bar magnet, such as the neodymium magnets used in this project. The Rosensweig crests maintain their smooth shape due to a balance between the stabilizing forces of gravity and surface tension and the destabilizing magnetic force [Lavrova, 2006]. Figure 4 shows this balance of forces for a single Rosensweig crest. The red arrows are the stabilizing forces and the green arrow represents the destabilizing magnetic force. Note that Figure 4 depicts a crest that is pointing upward, such as the crests formed on the bolt tip. While gravity plays a role in the force balance, surface tension is the dominant stabilizing force. This explains why the Rosensweig crests on the upper dish maintain the same shape even when turned sideways or upsidedown, as they are in the final image.

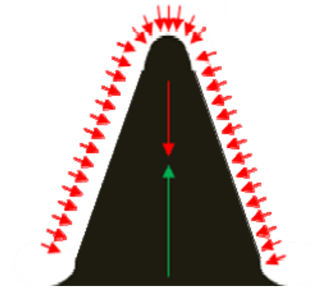

Figure 4: Force balance on a single Rosensweig crest

Working with Ferrofluid: Safety and Challenges

Ferrofluid is fairly safe to work with, but there are a few precautions that should be observed. If spilt on the skin, it should be washed off promptly with soap and water. Also, the small nanoparticles can set into small scratches on any surface it is spilt on, so it should be cleaned up immediately to avoid staining. It will also permanently stain clothing. Eye protection is recommended in case of an unexpected splash or splatter of ferrofluid.

The neodymium magnets are very strong, so care must be used when working with them. It may be hard to predict how the ferrofluid will react to a certain arrangement of metal objects and magnets, so one must exercise care to avoid splattering or spilling of the ferrofluid. Another important consideration is that in the presence of the magnetic field, ferrofluid will not behave as other common fluids. For example, when a full pipette of ferrofluid is brought close to a magnet, the magnet will pull the fluid out of the pipette, an occurrence which is difficult to control. It is important to work carefully and try to predict how the ferrofluid will behave to avoid spills and stains.

Image Discussion

I am very pleased with my final image. I think is very beautiful and also interesting. I think people will see my image and be very curious about what is happening, which is what I intended. My partner, Austin Ruppert, and I experimented with several different metal objects to use in our ferrofluid sculptures, most of which yielded very interesting and beautiful shapes. I am very pleased with the texture of the ferrofluid sculpture in my final image, as well as the strong contrast between the black fluid and the white background. I think the final image is captivating and wondrous, and I'm happy that we were successful in our efforts to create our own ferrofluid sculptures.

Acknowledgements

Thanks to Austin Ruppert for his ideas and assistance in creating and photographing the ferrofluid sculptures.

References

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Appendix

Original Photograph