Team Project 1: Ferrofluid interactions with Metal and Magnets

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Introduction

In the present day, a substance known as ferrofluid is becoming more and more of a commonly used material in multiple aspects of our world. Besides the amazing display of motion which can be seen by applying a magnet near the fluid, engineers are finding more and more applications for this useful material. What makes this substance so unique is what is emphasized by this photo in this project. This project explains why a fluid which conforms to a magnetic field can be useful and can show how this fluid interacts with other materials which can also be influenced by a magnetic field. The results of this project are somewhat intriguing and tell much more about how ferrofluid may be used in the present and future technological world we live in.

Behind the Physics of the Flow

The majority of the driving force behind this observed fluid flow is a magnetic field presence in the setup. While gravity will play a role due to the mass of the fluid, the majority of what is seen is a result of magnetic forces acting on the fluid. The intriguing factor in the flow is how the fluid interacts with the screw in the center of the setup, which has no pre-impose magnetic orientation in this project. While the screw is also magnetically affected by the magnets above and below it, the ferrofluid appears to interact solely with the bottom and top of the screw. It is intriguing that the ferrofluid does not interact with the middle of the screw.

Magnetic Fields can be described in multiple ways with multiple equations since a magnetic field directly relates to the orientation of electrons within an atom. For this project, van der Waals forces and magnetic forces work together to provide a fluid of microscopic magnetite pieces which do not clump together, but rather distribute throughout the liquid into a uniformly dense material. Van der Waals forces are also known as London dispersion, which is a weak force that attracts particles or molecules which temporarily or permanently have oppositely charged surfaces. What is unique about van der Waals forces are that it explains why water requires so much energy to turn from a liquid into a vapor, since hydrogen and oxygen provide a fairly strong attraction from their oppositely charged surfaces[2].

However, this is not the only force in action for ferrofluid, so the combination of magnetism, van der Waals bonding, gravity, and surface tension all contribute to the shape of the fluid and the direction in which the fluid flows. The nonpolar areas of the oil utilize van der Waals to stay in the liquid medium, while the polar areas of the oil utilize magnetism to attract the magnetite pieces in the oil medium.[1]

[1]"Ferrofluid." *Chemistry Comes Alive: Ferrofluid* 22 Nov. 1999. Web. 24 Mar. 2011

[2]Clark, Jim. "intermolecular bonding - van der Waals forces." 4 Aug. 2009. Web. 26 Mar. 2011.

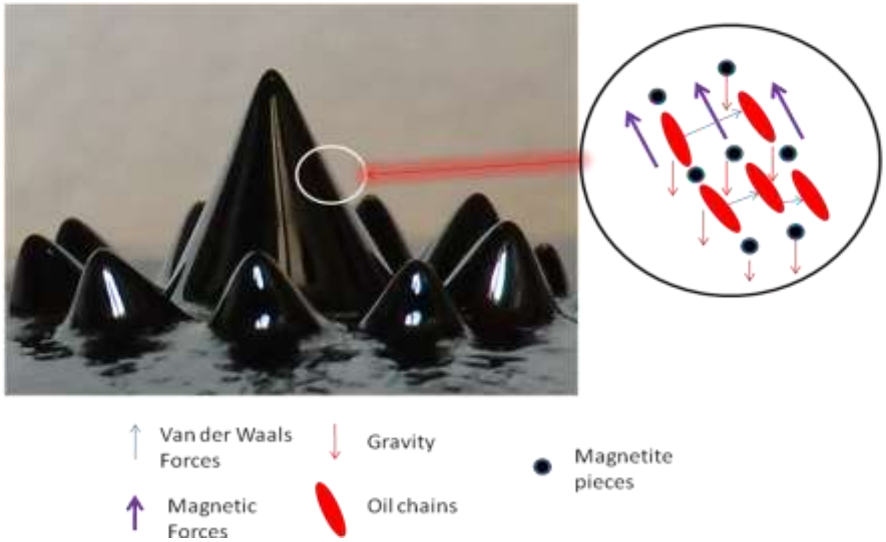

Figure 1: Free Body diagram of molecular interactions in ferrofluid.

When looking at the way the ferrofluid is positioned along the edges of the pictures, we see them go outward at various angles, all perpendicular to a field of magnetic lines we can visualize with the ferrofluid.


Figure 2: Magnetic Field around edges of ferrofluid on edges of magnets (not pictured)

Interestingly, the largest fluid accumulation is at the middle of the magnets on both sides, which is accentuated with the presence of the screw in the middle. This tells us that the screw contributes to the magnetic field strength in this area by the ferrous composition of the screw aligning from north pole to south pole However, they are accentuated mostly at the ends of the screw, producing the large fluid collection near the tapered side of the screw and a similar magnetic field on the head of the screw. This can easily be explained by realizing that no matter how a ferrous object or magnetic object is divided, there will always be a north pole and a south pole with opposite charge. This subdivision of north and south creates a bias in charge on each side, which in turn creates more of an attraction toward the pole when placed closer to such poles[1]. When the ferrofluid attracts to the screw, it attracts to the poles of the screw (the head and the tail) since they are the extremes of the system in terms of charge balance. Within each section of the ferrofluid, we can see that if the Van der Waals effect balances the magnetic field, then we see a pool of fluid with no directional bias in where it flows. However, when the magnetic force is stronger, then the resulting motion produces “spikes” readily discernable from the pool of ferrofluid surrounding it.

Set Up

The set-up of this project is quite simple. Using 8 DO-731003 Ceramic disc magnets, glue 4 of them in the very middle of opposite ends of the plexiglass where the ferrofluid will be flowing on. Slowly, pour 15 milliliters of ferrofluid on the very middle of the bottom plexiglass sheet, taking heed to not splatter all over the given area. It is recommended to place newspaper or a rag under the bottom sheet to prevent this. Place the top plexiglass side over the bottom plexiglass just enough to grab some of the ferrofluid on the clean side, close to the middle of the top piece. Move the top plexiglass piece away so that you can place the bottom of the nail on the ferrofluid side of the top plexiglass piece, allowing some of the ferrofluid to go toward the screw bottom. Next, place the top plexiglass with the screw over the bottom plexiglass piece to gather some of the ferrofluid to the head of the screw. Notice how the fluid only gets closer to the center of the screw as you move the two plexiglass pieces closer, not when you move them farther apart.

[1]Houston, Edwin James. *Magnetism*. New York City, New York: McGraw Publishing Co., 1905. Print.

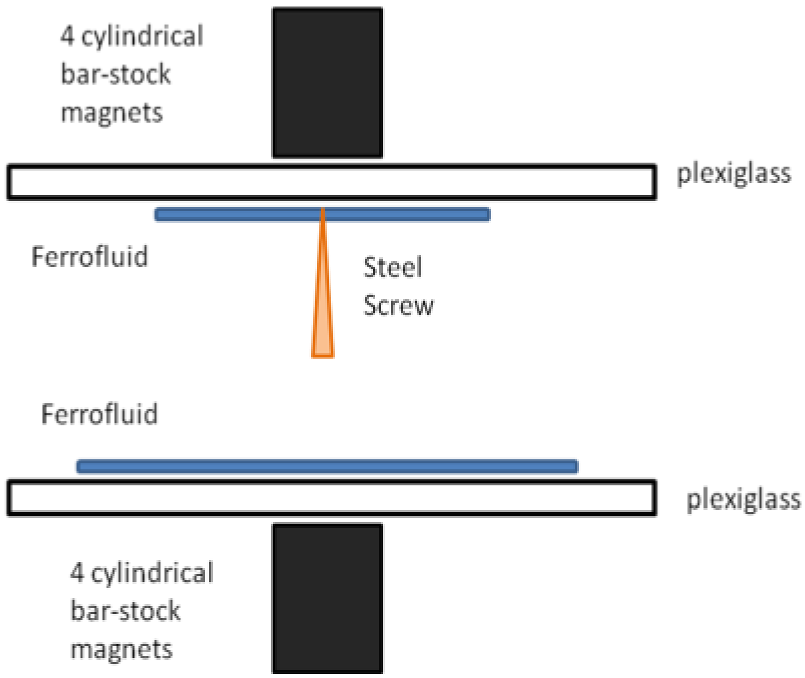

Figure 3: Set-up of ferrofluid on plexiglass with screw, seen from the side.

The camera used in this particular image is a Casio Exilim EX-H5 on March 5th, 2011 at 2:05 PM in Lafayette, CO. Because of the beautiful sunlight behind the camera, no extra lighting was used and a paper towel was adequate enough to provide just enough reflection to illuminate the stage area. At a pixel size of 2450 x 1860, the detail on the fluid flow provided enough information to adequately visualize what was going on with the fluid flow. On the aperture and specifications of the camera, an F-stop of 4.2 was used with an exposure time of 1/125th of a second and an ISO value of 400. The focal length was manually set to 10mm and created a maximum aperture value of 3.4 for this particular view. While most of the fluid flow here is quite simple, a good amount of the system needed to be seen in order to fully understand the physics behind the fluid flow.

Result

Ferrofluids have a very practical application in multiple aspects of our human life by having both the characteristics of a liquid and a ferrous metal. Typical applications today of this type of fluid is most readily found in printing ink because it can be controlled by an electromagnet within a printer which can then produce high quality print as fast as the letters can electronically change. In fact, to make a simple homemade ferrofluid, all you need is cooking oil and printer ink. What makes these results of this particular project interesting is the fact that fluid flow is not limited to the traditional forces which produce fluid flow. This picture itself shows how fluid flow is everywhere if analyzed properly.

What makes the ferrofluid so beautiful to use in fluid flow is the fact that the strength of the force to control it and the direction are easy to control. This can open multiple avenues in the field of nano-scale fluid flow and in nanocircuitry. Both the aesthetically pleasing sight of the ferrofluid and the physics which show the usefulness of ferrofluid make for a step into the field of flow visualization and how appreciation of creativity leads to improvement in technology and the betterment of society as a whole.