Flow Visualization

Get Wet Project

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The objective of this project was to gain practical experience capturing the behavior mechanics of ferrofluids. Ferrofluids are liquids which become strongly magnetized in the presence of a magnetic field. Upon first attempting this project I created a very weak household ferrofluid using a combination of roughly two parts mineral oil to one part black copy toner. I poured this mixture vertically in the presence of a magnetic field and captured the image deflecting towards the magnetic source. Later into the project however a shipment of EFH1 ferrofluid arrived. This ferrofluid is professionally made and orders of magnitude stronger than the homemade toner/mineral oil mixture. The EFH1 ferrofluid is strong enough that my original proposed project of capturing the deflection in air of the ferrofluid became less practical (The ferrofluid is so strongly attracted to the magnet that it became difficult to control the flow midair). Instead I captured several still images of the ferrofluid under varying magnetic field intensities.

In order to capture the still image I had to physically separate the ferrofluid from the magnets. When EFH1 physically comes in contact with a magnet it is extremely difficult to separate the two and for all effects and purposes the ferrofluid is lost. In order to prevent this phenomenon I always had a ¼ inch thick glazed ceramic tile located between the ferrofluid and the magnet. Whenever I wished to separate the two all that I had to do was detach the magnet from the tile and the ferrofluid would lose its magnetic polarity and become easy to handle once again. The glaze on the tile prevents the ferrofluid from being absorbed into the tile itself and makes cleaning up the experiment much simpler.

I placed roughly 10 mL of ferrofluid on the tile and then placed the tile on top of the magnet. For each successive image I used a different strength of magnet. The first three images had 1, 2, and 3, one inch circular ceramic magnets respectively. The fourth image used a single ½ inch neodymium magnet. A look at the Suratman number of the fluid reveals the relative significance of the needling due to the magnetic field vs surface effects. The Suratman number is the same as the Laplace number and is defined by the equation

$$La = Su = \frac{\sigma \rho L}{\mu^2}$$

Where sigma is the surface tension, rho is the density, L is the length of the characteristic sample, and mu is dynamic viscosity. The EFH1 datasheet lists the above values as surface tension = 29 mN/m, density = 1.21*10^3 kg/m^3, and dynamic viscosity as 6 mPa*s. The sample was roughly 3 cm in diameter. This gives us a value of

$$\frac{\sigma\rho L}{\mu^2} = \frac{(29 * 10^3)(1.21 * 10^3)(.03)}{(6 * 10^3)^2} = .02924 = \mathrm{Su}$$

This small Suratman number indicates that the surface tension forces are very small. It can then be stated that the surface tension forces play a very small part in the ultimate needling effect that we witness. This can be interpreted visually by looking at the fluid without the presence of a magnetic field. When simply left on the tile, in the absence of a magnetic field, the ferrofluid spreads out extremely thin. It does not "bead up" as a liquid with a higher surface tension would.

The image taken was simply the reflection of light off of the surface of the ferrofluid with a Canon SX130 IS PowerShot. The images were taken with strong ambient lighting (2x 40 Watt bulbs). The reason for this was that I decided to use a relatively long exposure time (.8s) with a low light sensitivity (400 ISO). I have found that the use of a flash is extremely counterproductive for use near EFH1 as it is a very reflective fluid and tends to produce images with far too much shine, as seen in the accompanying image.

Figure 1 - Example of a ferrofluid picture using a flash

I used a small gorilla grip tripod to get a fixed angle on the fluid for each successive image. In the final image however I did end up using a slightly smaller focal length (5mm instead of 7mm). I noticed that as the needling effect became more pronounced the diameter of pool reduced. This occurred simply because the same volume of fluid was occupying more space vertically than it had previously. However in order to get side by side images I had to zoom in slightly to get them to be the same size. Even in my final image however I also needed to scale up the fourth ferrofluid picture by about 15% in gimp in order to get it to match the other three images. The images were cropped out using the free select tool in gimp. I found that the fuzzy select tool was not precise enough to capture the boundaries of the ferrofluid. I copied each of the 4 images into one composite image and then used the blur tool around the image edges to soften their appearance. I used a very slight color filter to increase the contrast of the black image on the white background. Each of the original images was take with 4000x3000 resolution with a f/8 f-stop. The image was taken from 5 inches away at a roughly 30 degree downward angle.

Ultimately I was very satisfied with my project. I think that it does a good job of portraying how a ferrofluid reacts under different strength magnetic fields. I would like to see if I could carry this further and capture video of the same type of procedure. If I could get an electromagnet and vary the strength of the field over time I think I could get a more impressive image. I'd also like to see if I could capture the change in a ferrofluid using a high speed camera. Some of the most dramatic images I could image capturing with a ferrofluid are not the images that you see when the fluid is stable but rather the movement of the ferrofluid as you change the magnetic field. Using a normal camera and trying to capture such an image would be extremely difficult but with the high speed camera I think I could capture a high