Visualization of Magnetic Waves using Ferrofluid

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Figure 1. Rayliegh-Taylor Instability demonstrated by Acrylic Paint Pour

Background

The artistic intent of this photograph was to create an aesthetically pleasing and symmetrical pattern. However, the scientific intent of this photograph was to visually depict magnetic waves using ferrofluid. Ferrofluid contains magnetic particles that align with the magnet's magnetic field. As the particles align, the fluid begins to act as a solid, creating the spiked pattern found in figure 1.

Set Up

This experiment was conducted using ferrofluid produced by the company Ferrotec. The specific type of ferrofluid used was EFH1, the properties of which are listed in figure 2. To capture this image, approximately 1 tablespoon of ferrofluid was poured into a 4.25 in x 4.25 in x 2.25 in square glass Tupperware bowl. The bowl was placed on top of a flat circular magnet about 2 inches in diameter. The photograph was taken outside, and only natural lighting was used for illumination.

EFH1 Specifications and Physical Properties

Appearance	Black-brown fluid	
Carrier Liquid	Light Hydrocarbon	
	CGS Units	SI Units
Saturation Magnetization (Ms)	440 Gauss	44 mT
Viscosity @27°C	6 cP	6 mPa·s
Density @25°C	1.21 g/cc	1.21 10^3 kg/m^3
Pour Point	-94 °C	-94 °C
Flash Point	92 °C	92 °C
Initial Magnetic Susceptibility	0.21	2.64

Figure 2. Ferrotec Ferrofluid Properties

Physics of the Fluid

Ferrofluids are fluids that contain superparamagnetic particles that have been suspended within the liquid. The particles are usually iron but may also be cobalt or nickel [2]. Superparamagnetic materials are only found on the nanoscale and only behave like a magnet in the presence of a magnetic field [3]. Therefore, in the presence of a magnet, the particles, and by proximity, the entire fluid becomes magnetic and acts as such. This magnetism of the ferrofluid manifests itself in the real world as the peaks seen in figure 1. Each peak directly reflects the magnetic field of the magnet that's been applied to the fluid [4]. This is known as the normal field instability. The peaks can be used to determine whether the magnetic field is strong enough for the fluid to form into a stable configuration. A stable configuration is demonstrated by peaks in a hexagonal pattern. An unstable configuration would have a square pattern, as seen in our image [5].

Visualization Techniques

To capture this image several people took pictures throughout the experiment, using a verity of cameras and lenses. Each camera was set to different settings to obtain the best image. The key was to minimize light reflection off the ferrofluid. The photos that did this best were the ones that were taken with the fluid in a shadow while allowing the natural light to illuminate it.

Photographic Techniques

For the image selected, the camera used to take this photograph was the Canon EOS 5D Mark III using a Canon EF 24-70 mm lens. The image was taken using the characteristics listed in Table 1. Spatial and temporal resolution were also calculated at 2 decades and 3 pixels respectively. Since there is no velocity associated with the image, the temporal resolution can be attributed solely to motion blur. For the purposes of the experiment, both estimations are reasonable and allow the flow to be accurately captured [6].

Table 1. Camera Specifications for the Photograph

Specification	Description
Aperture	f/4.5
Exposure	1/350
ISO	640
Focal Length	70 mm
Focal Distance	0.37 m

Following selection of the image, post processing was conducted to enhance the artistic and scientific quality of the photograph. The original image selected was 5794 pixels by 3868 pixels. This was cropped down to 944 pixels by 630 pixels. After the image was cropped, the RGB curve was adjusted to slightly brighten the peaks and valleys of the ferrofluid points. Local contrast detail and midtone range and the image sharpness threshold were also increased to clearly delineate the peaks from one another. Finally, the exposure was increased to further brighten the photograph.

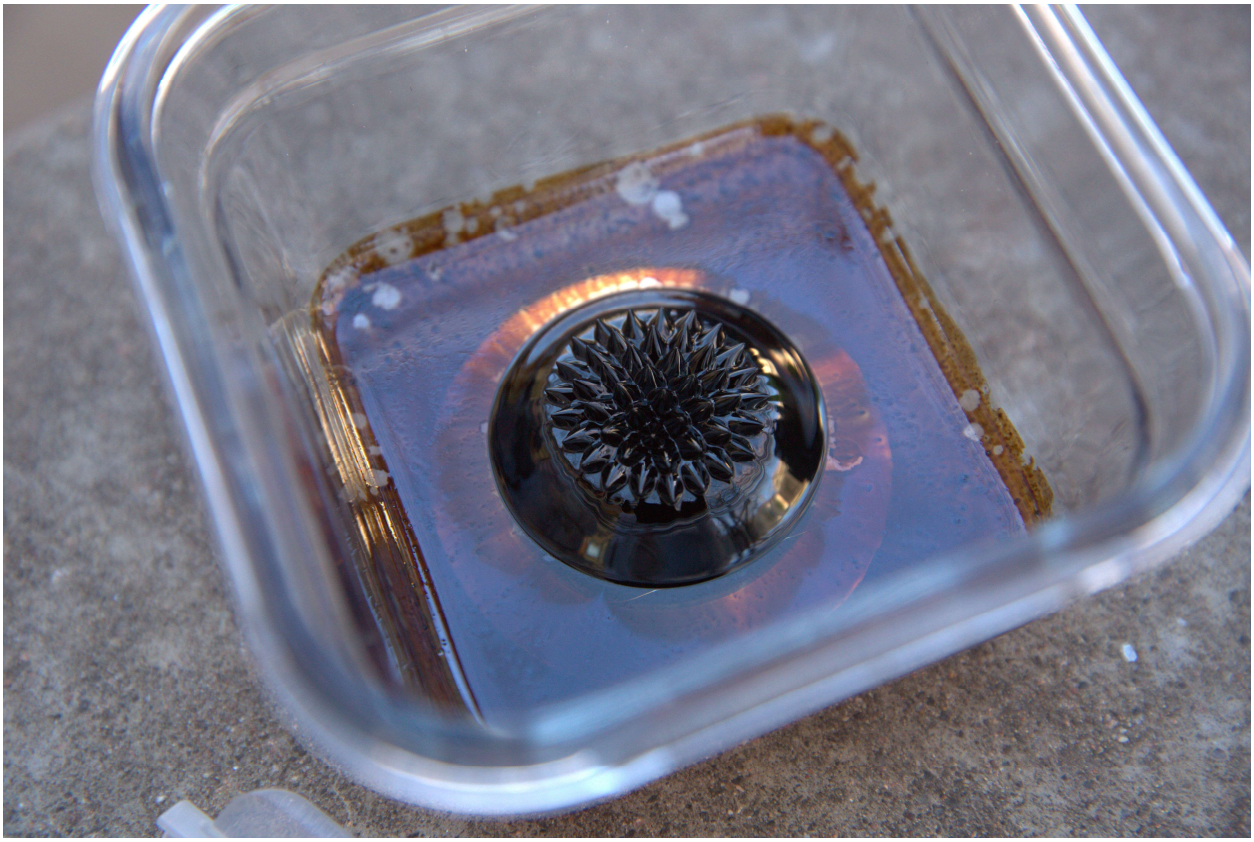

Figure 3. Original RAW Image

Conclusions

This image was very simple to create and yielded very pleasing results. There are ways to change the color of the ferrofluid, which I would like to do in future iterations of this experiment. The black color yields an image that could be abstract art of sorts, but I believe color would enhance the artistic quality of the photo. Additionally, I would like to change/use electric lighting to reduce the reflection off the

ferrofluid. Overall, I think this is a good experiment that both yields an artistic photo while also demonstrating scientific principles.

References

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