High Speed Ferrofluid Visualization

Joshua Bourquin
University of Colorado

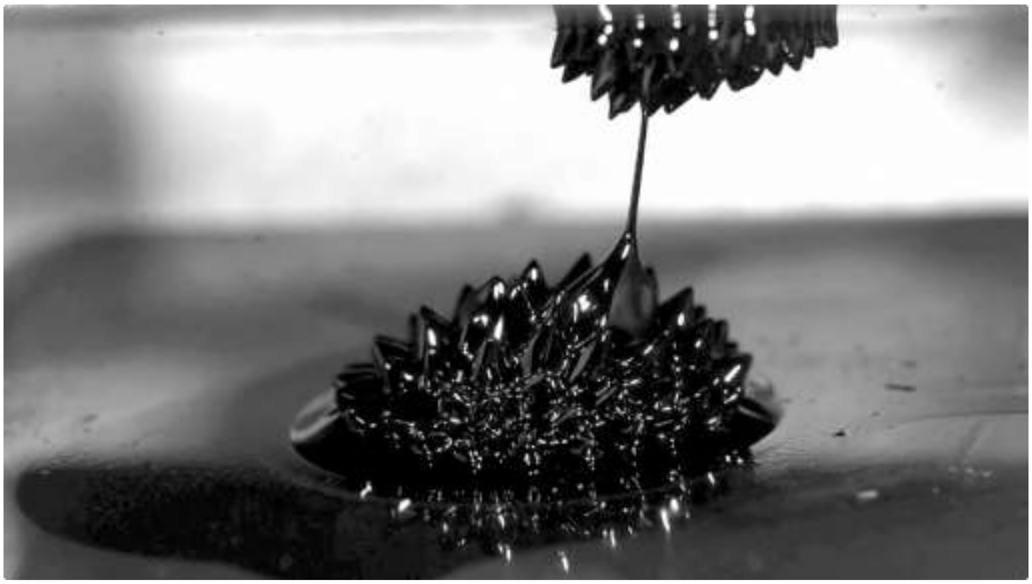

Figure 1. *High-speed video snapshot of ferrofluid being pulled between two vertically opposed magnetic fields.*

I. Introduction

Ferrofluids are a colloidal dispersion of ferromagnetic particles residing in a carrier liquid that in turn causes the liquid to react in the presence of a magnetic field. In order for the suspension of particles to remain stable (i.e. evenly dispersed) in the presence of a magnetic or gravitational field, the particles are generally sized to fall within the nanoscopic range. The carrier liquid of the ferrofluid also tends to be low viscosity, low vapor pressure, chemically inert and thermodynamically stable in the presence of a magnetic field.[1] Combined, these properties give the fluid exceptionally unique fluid dynamic characteristics. Figure 1 is a high-speed video snapshot of ferrofluid being pulled between two vertically opposed magnetic fields.

II. Experimental Setup and Analysis

The experimental setup for the high-speed video simply consisted of a small amount of ferrofluid sitting between two plates with neodymium magnets resting on the opposite side of each plate from the ferrofluid. By slowly moving the magnets on either the top or the bottom plate, one was able to adjust the magnetic fields such that a small quantity of ferrofluid could be pulled from one plate to the other. This phenomenon is readily demonstrated in the video as a stream of ferrofluid is pulled from the top plate to the bottom till the viscous forces holding the stream together break, releasing ferrofluid droplets that fall towards the strongest magnetic field acting on them either up or down respectively. One of the properties of ferrofluid that allows for this transfer of material from one plate to other is an increase in fluid viscosity in the presence of a magnetic field commonly referred to as a magnetoviscous effect. This phenomenon of field dependent changes in viscosity, as described by experimental results, is directly linked to chain formations of a small fraction of large particles in the fluid. The smaller particles in the fluid have very little effect on the viscosity and actually behave in a Newtonian manner as the fluid normally would in the presence of zero magnetic field.[1]

III. Visualization Technique

The high-speed video did not require any special visualization techniques to speak of as the ferrofluid itself produces highly specular reflections and is easy to visualize even under normal lighting conditions. The dark color of the ferrofluid does however benefit from a lightly colored background to enhance contrast of the image. Lighting for the video was provided by two Vision Research NorthStar high-intensity 250W light sources. It is interesting to note that the frequency of the light sources was not sufficient to produce consistent lighting for video's frame rate causing the light to pulse in the video.

IV. Photographic Details

The video was captured using Vision Research's Phantom Flex digital cinema camera at a frame rate of approximately 2000 fps with an imaging resolution of 1920x1080 pixels.[2] The video was recorded in the camera's native cine video format and then converted to a Quicktime mov video format to ease post processing. The original full-length video was then edited down to the last 15 seconds, converted to a black-and-white color spectrum, and cropped in post processing using Apple's iMovie video editing software to produce the final video, a snapshot of which can be seen in figure 1.

V. Conclusion

The high-speed visualization of ferrofluid acting between two magnetic fields provides some insight into the unique properties of the fluid. Readily demonstrated in the video are the viscous variations of the fluid under the influence of a magnetic field and the magnetic properties of the fluid as it forms spikes along the field lines of the magnets. What I find most impressive about this material is that it appears to retain theses shapes and properties even in the presence of an opposing gravitational field.

References

1. Odenbach, S. *Ferrofluids Magnetically Controllable Fluids and Their Applications*. Berlin [etc.: Springer, 2002. Print.
2. http://www.visionresearch.com/Products/High-Speed-Cameras/Phantom-Flex/