Visualization of Magnetorheological Fluid Experiencing Magnetic Field

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MCEN 5151: Flow Visualization
Image/ Video 4

University of Colorado Boulder

November 16, 2022

Figure 1: Magnetorheological Fluid Experiencing Magnetic Field

For this fourth Image/ Video submission, students were set out once more into teams to explore fluid flow phenomenon. My team initially intended to explore the magnetic properties of ferrofluid, however we obtained a unique magnetorheological (MR) fluid instead that acted similarly, but featured quite different properties. For example, ferrofluid acts much more like liquid, but this MR fluid experienced non-newtonian properties that were very similar to mud, and it also was intended to stiffen, or undergo rheological effects, when experiencing a magnetic field. It was possible to see the individual grains of iron within this fluid, while with true ferrofluid, the particles are not visible to the naked eye. To experiment with the rheological fluid, we used a large 5" diameter magnet positioned below to see the stiffening effects. Bryce was in control of the magnet, while myself, John, and William played with the lighting on the fluid and took photos. The final image captured is displayed below in Figure 1.

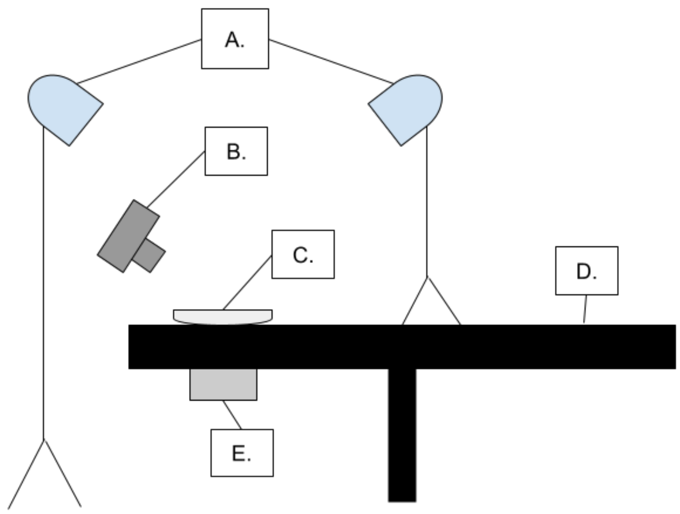


Figure 2: Experimental Setup for Figure 1

Figure 2 shows the experimental setup used to take Figure 1. The elements labeled are described in Table 1:

Table 1: Figure 2 Items and Descriptions

Item	Description
A	LED Lights on Tripod
B	Handheld Nikon D3400
C	White Ceramic Plate Containing Magnetorheological Fluid
D	Wooden Table (2.5” thick)
E	Magnet (5” diameter)

Magnetorheological fluids have applications in the use of damped systems, such as those featured in vehicle suspension, aircraft movement control systems, and more. According to Genç and Phulé, the ‘off’ state of the fluid in which no magnetic field is applied makes the fluid similar to the viscosity of paint, and when ‘on’ (in the presence of a magnet) the fluid experiences a significant increase in its static yield stress (Genç, 2002). In the context of the fluid shown in Figure 1, this is the reason that the triangular spikes begin to form along the surface. The boundaries of each spike are determined by the relative ratio of iron particles to oil present, as the regions with a greater concentration of oil will cause there to be less force required to pull the fluid out from the surface horizon due to the lower yield stress in these regions. An equation that models this static yield stress is given in Equation 1:

$$\tau_{ys} = (6^{1/2})\phi\mu_0(M_s)^{1/2}H^{3/2} \tag{1}$$

In this equation, ϕ is the particle volume fraction, H is the applied magnetic field, and $\mu_0 M_s$ is known as the saturation magnetization (Genç, 2002). Using this equation, one could calculate the amount of stress that the fluid could sustain when a known field is applied.

When presented with a changing magnetic field, one must also consider the nonlinear case of magnetism, where the fluid experiences ‘magnetic saturation’ (Ginder, 1998). In these cases, one must be aware of uneven spacing between the iron particles, however such analysis is outside the scope of this course.

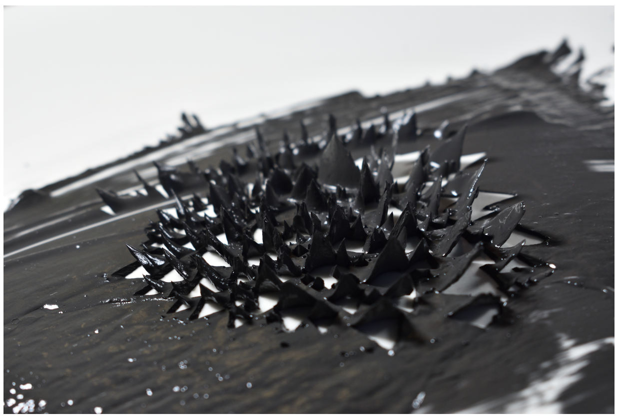
The goal of this assignment was to visualize the effects of a magnetic field acting on an MR fluid and see what sorts of patterns would emerge. Figure 3 shows a photo of the bottle of fluid used.

Figure 3: Bottle of Magnetorheological Fluid Used for Visualization

This fluid consisted of two components– metal particles that reacted to the magnet, and a thin oil that contained these particles to allow for flow. There was a large amount of separation between the oil and the metal flakes, which caused differences in the fluid’s viscosity when there was more or less oil present. About 2 cups of the fluid were poured from the container in Figure 3 into a smaller Tupperware container. The procedure used was as follows: a wooden popsicle stick was used to scoop a small amount of the MR fluid onto a white ceramic plate. Photos were then taken of the fluid while a magnet was moved around underneath the table. More fluid was then added over several different rounds, and at the end a higher ratio of oil was added to the metal to see what would happen. For the result in Figure 1, more oil was present in the mixture. The lighting used was a combination of an overhead fluorescent lamp, daylight, and two SAVAGE brand 35W 5500K LED bulbs with a white light setting producing 2130 lumens. For some of the shots, I also experimented with the built-in flash on the Nikon D3400, however it was not used to produce Figure 1.

The submitted photo was taken with a Nikon D3400 DSLR camera. The photo was taken with a focal length of 46mm at aperture f/8, ISO of 320 and shutter speed of 1/100s. Exposure compensation used was -0.7 EV. The goal of framing of the image was to capture the entire region of the magnetic field's effect. The FOV of the unaltered image spans a region of approximately 12x16 inches (at 6000x4000 pixels), however the cropped image in Figure 1 spans approximately 6x8 inches at 2843x1903 pixels.

In order to emphasize the 'spikes' from the magnetic field, I decided to crop the original image to the bottom left corner. I felt that this struck a nice balance between the muddy section and the spiked region. I also applied a monochrome filter to remove the blue hues in the original image, increased the contrast, and added a slight vignetting effect to produce Figure 1. The side-by-side comparison of the original and altered images is shown below:



(a) Original Photo (6000x4000)

(b) Edited Photo (2843x1903)

Figure 4: Original vs. Edited Photo

In conclusion, Figure 1 highlights the behavior of this magnetorheological fluid as it experiences effects from a strong magnet. I am mostly happy with the way that the photo turned out– I wish that I had used a smaller aperture such that some of the features on the right side would be more in focus. Otherwise, I am pleased by the cropped image! I feel that I was successful in capturing this neat flow phenomenon and would not change anything in the experimental procedure.

References

Genç, Seval, and Pradeep P Phulé. \Rheological Properties of Magnetorheological Fluids." Smart Materials and Structures, vol. 11, no. 1, 2002, pp. 140{146., https://doi.org/10.1088/0964-1726/11/1/316.

Ginder, John M. \Behavior of Magnetorheological Fluids." MRS Bulletin, vol. 23, no. 8, 1998, pp. 26{29., https://doi.org/10.1557/s0883769400030785.