Group Project #1 Assignment

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1. Introduction

The purpose behind this report is to describe the techniques used to capture an image of ferrofluid under the influence of magnets and describe the physics behind the flow phenomena seen in the cover photograph. For the first group assignment ferrofluid was chosen as the experimental fluid because of its interesting properties and demonstrated behavior when it interacts with magnets. The captured image shows a normal field instability or Rosensweig instability, and was achieved by holding one magnet under a plate of ferrofluid and one above the fluid to form spikes. The following text describes the physics behind the normal field instability, how the flow was achieved, and photographic techniques used to achieve the best possible picture. Several different ferrofluid setups were used during the group project, including using an electromagnet and metal sculpture, but this image was chosen because it clearly showed the large spikes that can form when the ferrofluid interacts with magnets.

2. Experimental Setup

For this experiment an aluminum tray about 1' in diameter was filled with ferrofluid to a depth of approximately 0.2". The tray was placed on a thin 3" wide wooden beam that was attached to two vertical support beams. Another wooden beam was attached to the vertical support beam and its height was adjusted so that it was about 5" above the tray that contained the ferrofluid. A small magnet about 1" in diameter was placed on top of the upper beam and a larger magnet of approximately 3" in diameter was held under the bottom beam directly under the tray to start the ferrofluid interactions with the magnet.. A camera attached to a tripod was setup about one foot away from the tray and its height adjusted so that it was slightly looking down on the tray. A spotlight with a diffuse hood was placed behind the camera and slightly to the right to provide lighting to the setup. Figure 2.0-1 shows the experiment setup and the placement of the camera and lighting. The placement of the lighting highlighted the fluid well, but produced bright reflections on the aluminum tray so black electrical tape was place around the rim of the tray to reduce reflections.

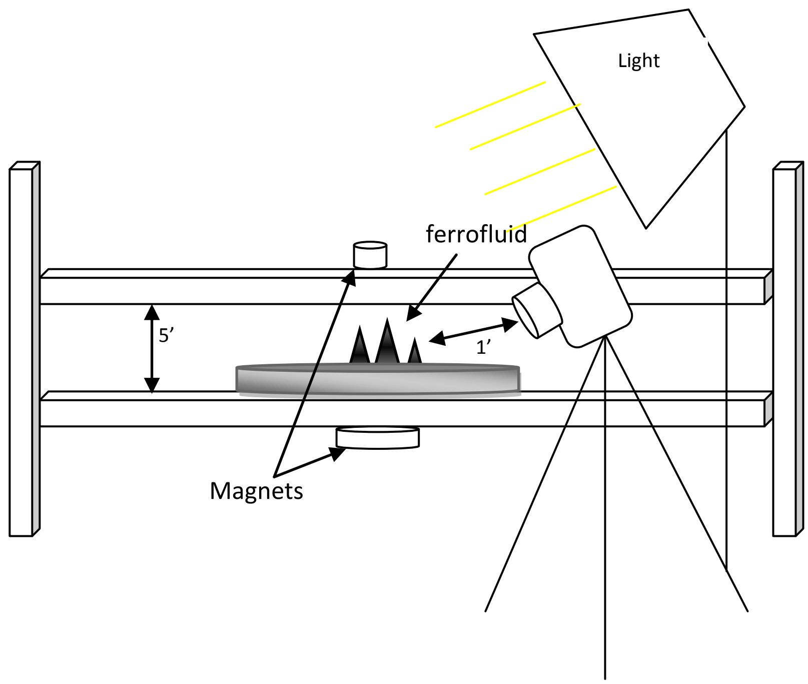

Figure 2.1 Experimental Setup

3.0 Description of Flow Physics

Ferrofluid is a colloidal liquid that consist of small particles of ferromagnetic material roughly 10nm in size suspended in a carrier fluid such as oil [1]. A surfactant is added to the liquid and bonds to the individual particles and prevents the magnetic material from forming clumps. The nanoparticles of magnetic material also do not generally settle over time contributing to the overall magnetic response of the fluid. In the presence of a vertical magnetic field, as is the case for this experiment, the ferrofluid takes on the appearance of spikes forming a uniform pattern of peaks and valleys. This phenomenon is called normal-field instability or Rosensweig instability. This instability seen in the ferrofluid is driven by several forces, including magnetic forces, surface tension, and gravity [2]. The magnetic force between two magnets is specified by the equation (1), where m is the magnetic moment and B is the magnetic field. For this experiment the strength of the magnets were unknown.

$$F = \nabla (m \cdot B) \tag{1}$$

The peaks in the ferrofluid form when the magnetic energy can outweigh the effects of gravity and surface tension. The ferromagnetic material wants to align with the magnetic field produced from the magnets. At the same time gravity is acting to pull down the ferrofluid as is surface tension. Figure 3.0-1 shows a diagram of the magnetic field lines between two opposing magnetic poles. The figure represents how the two magnets were oriented for this experiment.

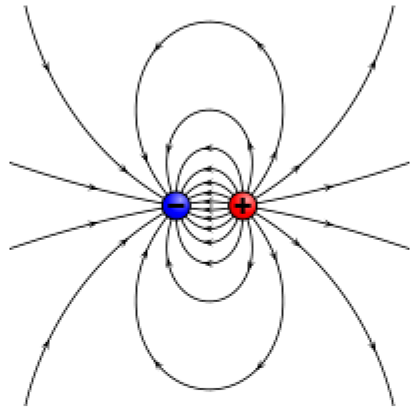

Figure 3.0-1 Magnetic Field between Two Opposing Magnetic Poles

For this experiment the picture was taken while the bottom magnet was being moved so all the spikes on the bottom surface tend to angle to the left slightly. The top magnet was held in place, which allowed you to see how the small spikes align with the magnetic field. On the bottom surface you can see that the magnetic field is strongest in the center creating the largest spikes and even overcoming the forces of gravity and surface tension by pulling the ferrofluid up to the top surface. Overall the photograph captures the fluid flow phenomenon well by showing the direction and strength of the magnetic field, and the how gravity and surface tension pull down on the ferrofluid helping create the spikes seen in the photograph.

4.0 Photographic Technique

A Canon EOS 7D DSLR 18 MP camera was utilized for this photograph. The 100 mm macro lens was used to get a clearer close up photograph. The field of view of the photograph was roughly 6” x 5” and the camera was placed roughly 1’ from the front of the ferrofluid tray. The exposure mode was set to manual with a shutter speed of 1/160s. The focal length used was 100mm and the aperture was set to F-3.5. The ISO was 800 and lighting provided enough light so the flash was disabled. Figure 4.1 shows the before and after Photoshop processing photograph. Post processing in Photoshop included converting the photo to black and white to create more drama. The brightness was decreased slightly to make the highlighting on the ferrofluid not as overpowering. Some reflections on the aluminum tray were removed and the photo was cropped slightly to remove the blurring from the out of focus wood support beams.

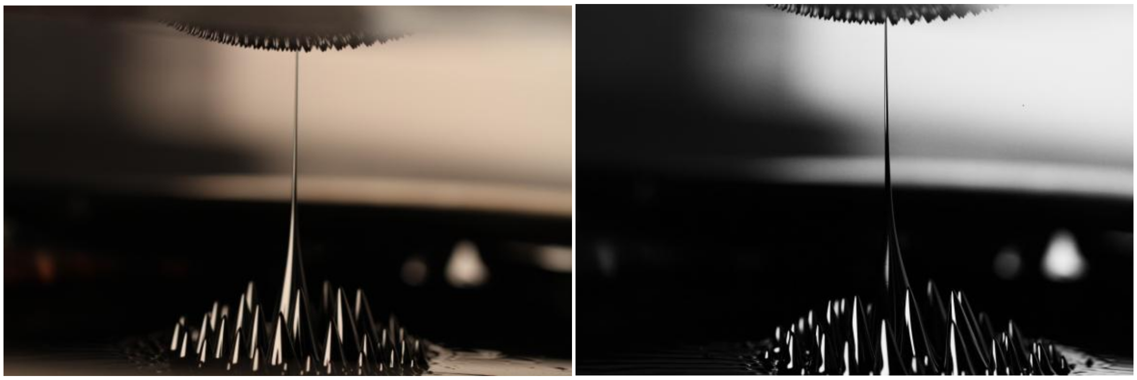

Figure 4.1 Pre and Post Processing Photograph

5.0 Conclusion

This image demonstrates how a ferromagnetic fluid behaves under the influence of a vertical magnetic field. When a strong enough magnetic field is present the ferrofluid wants to align itself with the magnetic field lines, however other force are acting on the fluid such and gravity and surface tension. These forces pull down on the ferrofluid while the magnetic forces are pulling up. The combination of these forces creates the peaks and valleys that are shown in the photograph. These peaks and valleys demonstrate what is called normal field instability. The biggest issue with this assignment was that we had to use one camera to take photographs due to the tight spaces. Transferring of the large photographs proved to be difficult because they could not be sent over email. For future group projects transfer devices such and thumb drives will help with getting all the images to each teammate immediately after the photo session. I would have also liked to have more practice using my camera, but the team stuck to using the nicest camera in the group.

6.0 References

1. O. Lavrova, V. Polevikov, L. Tobiska, “Numerical study of the Rosensweig instability in a magnetic fluid subject to diffusion of magnetic particles,” Mathematical Modeling and Analysis, 3879 (2010).

2. C. Gollwitzer, A.N. Spyropoulos, A.G. Papathanasiou, A.G. Boudouvis, R. Richter, “The normal field instability under side-wall effects: comparison of experiments and computations,” New Journal of Physics, Vol. 11, 053016 (2009).

3. http://en.wikipedia.org/wiki/Ferrofluid