Playing with Ferrofluid

Group Image #2
MCEN 4151: Flow Visualization
Professor Jean Hertzberg

Alex Unger

(alex.unger4@gmail.com)
Mechanical Engineering, University of Colorado at Boulder

University of Colorado Boulder

I. Introduction

This video was captured for the second team image submission for the course Flow Visualization: The Art and Physics of Fluid Flow. Our group, consisting of Scott Hodges, Zac Rice, and myself, was interested in the beautifully peculiar flow created by introducing a magnetic field to ferrofluid, a fluid that reacts to magnetic forces. After attempting to make our own ferrofluid with ink toner and failing to acquire any locally, we decided to source the ferrofluid from a display located at the Integrated Teaching and Learning Laboratory (ITLL) at CU-Boulder.

II. Flow Apparatus

As mentioned above, a ferrofluid display at my school was used to capture the flow of the ferrofluid. This display features an electromagnet underneath a spiral-shaped steel structure sitting in a pool of ferrofluid. A model of the display is shown below in figure 1. Note that the arrows in the figure indicate the direction of ferrofluid flow.

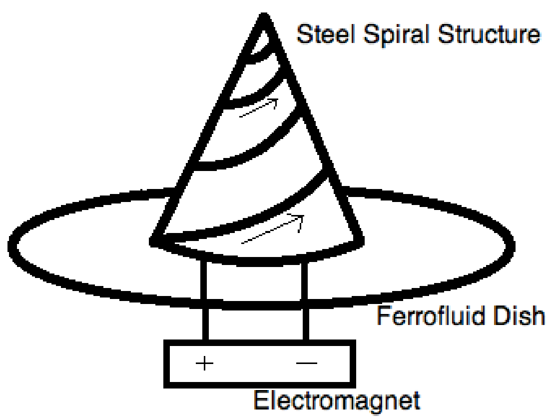

Figure 1: Model of Flow Apparatus

III. Fluid Dynamics

Ferrofluids are created by dissolving nano-sized particles of a magnetic material (iron is commonly used, hence the "ferro") into a liquid carrier (oil is commonly used). The magnetic particles are treated with a surfactant to keep them separated; otherwise the particles would all clump together when exposed to a magnetic field.[1]

The flow up the spiral grooves in the steel structure is driven by the electromagnet underneath the display. The electromagnet produces an electric current through the steel, which induces a magnetic field and draws the magnetic fluid up the spirals. The magnetic field exits along the spiral and wraps around to the bottom of the steel structure. A representation of the magnetic field is shown in figure 2 on the following page. Note that in actuality, the magnetic field is not concentrated into lines until it interacts with the ferrofluid.

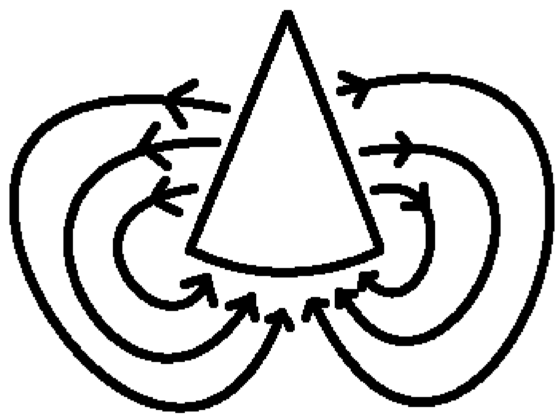

Figure 2: Model of Magnetic Field

The magnetically charged ferrofluid want to follow and align itself with the magnetic field direction, but surface tension and Van der Waals forces oppose the magnetic force. The equilibrium between these forces results in the cylindrical pyramid spike shapes associated with magnetically charged ferrofluid, an effect known as normal-field instability.[1,2]

IV. Image Capturing Techniques

After first playing around with the ferrofluid display, I decided capturing the ferrofluid flow from directly above the spiral structure would give an interesting and aesthetically pleasing perspective. A case around the display created problems for filming the flow because it caused a lot of reflection. As such, I decided to capture the video from my iPhone 4. By placing the camera directly above the center of the spiral, the lens was only a couple millimeters away from the display case, which I found significantly reduced the amount of glare and reflection in the image. The lens was approximately 6" away from the tip of the steel structure, which itself is approximately 8" tall, giving a overall focal length of 6"-14". The iPhone's f/2.8 lens allowed for a large depth of field to keep the entire image mostly in focus. The 720x1280 pixel video was captured at 30 fps and played back in real-time. The frame covers an area of approximately 12" wide 8" long.

Two fluorescent ceiling lights with two bulbs each provided lighting for the image. The lights were spaced about 15 feet apart, and the ferrofluid display was placed in the center to minimize reflections.

A series of slight modifications were made to the original video. After being imported into Adobe After Effects, the video was rotated 90° and cropped. I then used the curves tool to saturate the lightest colors to complete white. This eliminated some of the noise in the glare by turning it all to a uniform white. This also served to increase the contrast and produce a clearer, sharper image. Before and after editing photos are shown in figures 3 and 4 below.

Figure 3: Before Editing

Figure 4: Post-Editing

IV. Conclusions

This video succeeds in demonstrating the beautiful flow associated with magnetically charged ferrofluids and gives clues to the physics behind the spectacular and unique flow. Although the iPhone image doesn't provide the optimal resolution, the art and physics of the flow are shown accurately. Post processing helped clean the image up and better reveal the flow, but for future work I think it would be best to use a better camera or camcorder in capturing ferrofluid flow. I also think that diffusing the light source could optimize the lighting in the video. Overall, I am pleased with the end result, but there is definitely room for improvement.

V. References

1] "Ferrofluid: Magnetic Liquid Technology". *Ferrotec.* Ferrotec Corporation, 2014. April 7, 2014 .<https://www.ferrotec.com/technology/ferrofluid/>.
2] "Ferrofluid Fun". *Physics Central*. American Physical Society, 2014. April 7, 2014. <http://www.physicscentral.com/explore/action/ferrofluids.cfm>.

VI. Acknowledgements

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