Mechanical Engineering
University of Colorado Boulder

Team Second Report

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Contents

1 Background

Figure 1: Team Second Submission
(video url: `https://youtu.be/rmcj0mpkqWo`).

The figure above is the final video that I submitted for the Team Second assignment. I set out to capture the effects of a magnetic field on ferrofluid. In my first attempt, I captured still images of ferrofluid inside a glass container. I wasn't satisfied with the aesthetics or the flow so I continued experimenting. My second attempt involved placing ferrofluid on a flat surface and moving it with a magnet. While experimenting, I decided to include whiteboard cleaner fluid (isopropyl alcohol) on the surface in the mixture with the ferrofluid. Both the flow and aesthetics were interesting and I decided to record a video of the interaction. My team for this project consisted of Aaron, Evan, Robbie, and Max. Our entire team collaborated in the first attempts. Aaron and I worked together on later attempts.

2 Flow Apparatus and Flow Description

Figure 2: Flow apparatus materials (figures are not to scale).

To capture the final video, we used the materials in figure 2. The whiteboard we used is a 4' x 6' aluminum frame whiteboard. We placed the whiteboard on a table so that the white surface faced the ceiling. Half of the whiteboard sat on the table, while the other half was suspended in the air. On the suspended side we put 30 ml of ferrofluid directly on the surface. Then, we sprayed about 15 ml of whiteboard cleaner fluid (primarily made-up of isopropyl alcohol) on top of the ferrofluid. In this experiment we used a neodymium disk magnet. The magnet was then placed underneath the surface of the whiteboard. We arbitrarily moved the magnet in different directions along the inferior surface. This movement caused the ferrofluid magnetic particles to move with the magnet. This is the flow that was capture in the video I submitted for this assignment.

Ferrofluids contain magnetic nanoparticles that are suspended in a carrier fluid. The carrier fluid is a mixture of an organic solvent like corn oil with a surfactant like sodium stearate (most common molecule found in soap). A typical ferrofluid contains five percent magnetic particles, ten percent surfactant and eighty five percent carrier fluid [1]. In the ferrofluid mixture, the surfactant molecules form layers of charge around the magnetic nanoparticles (see figure 3). The groups of surfactant-coated nanoparticles repel each other in the solution. This prevents clumping of the nanoparticles in the fluid mixture. The particles are randomly aligned throughout the fluid in the absence of a magnetic field. But, in the presence of a magnetic field, the particles align with the field. The classic 'spikey' appearance of ferrofluid in the presence of a magnet is a result of the surfactant-coated nanoparticles aligning with the magnetic field lines of the magnet.

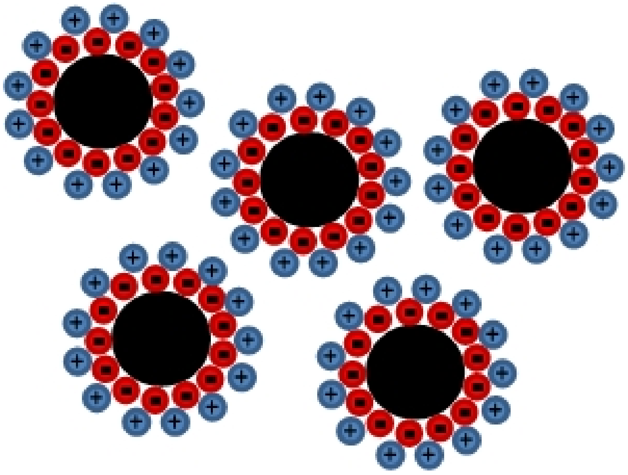

Figure 3: Ionic surfactant surrounding magnetic nanoparticles.[1]

The fluid I captured in the video is ferrofluid that was sprayed with isopropyl alcohol. The ferrofluid we used was an oil-based ferrofluid; the carrier fluid in our solution was corn oil. In figure 4 you can see the intact ferrofluid we started with on the left and the ferrofluid that we sprayed with isopropyl alcohol on the right. The isopropyl alcohol is miscible (able to mix) with corn oil. Being that the ferrofluid is eighty five percent corn oil, it will mix well with the isopropyl alcohol.However, we did not mix-in the substances prior to placing them on the whiteboard surface. We sprayed the isopropyl alcohol on a specific area after the ferrofluid was already on the surface. You can see that the substances mixed slightly in the faint-brown regions. The white regions are places where the isopropyl alcohol has not yet mixed with the solution. Moreover, some of the ferrofluid adhered to the surface of the whiteboard, while some was suspended above the isopropyl alcohol due to the difference in densities. We were able to move the dense patches of ferrofluid with the magnet.

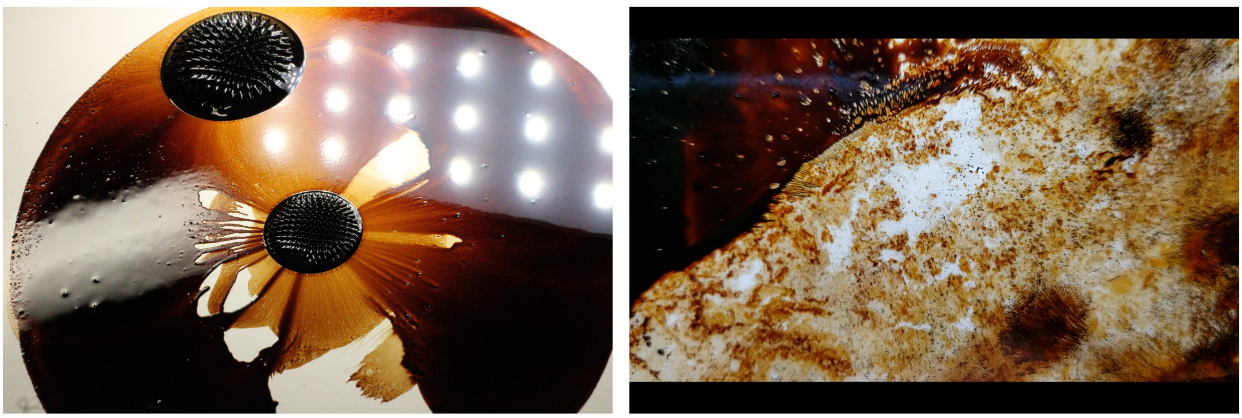

Figure 4: Ferrofluid with (left) and without (right) isopropyl.

The video I recorded gave me a lot of information about the movement of the particles in the magnetic field. I was able to get the velocity by looking at the distance a specific particle moved every second. I obtained two frames that were one second apart. Using Photoshop's measurement tool, I was able to find that one particle moved with a velocity of 0.0007 $\frac{m}{s}$. The following values were used in my calculation:

- Distance moved by a particle: 0.26 pixels
- Distance of field of view in pixels: 25.36 pixels
- Distance of field of view in meters: 0.069 meters

Using the values listed above, I created ratio between the pixel distance and the corresponding meter distance.

$$\frac{particle\ distance\ in\ pixels}{total\ distance\ in\ pixels} = \frac{particle\ distance\ in\ meters}{totaldistance\ in\ meters}$$

$$\frac{0.26}{25.36} = \frac{x}{0.069}$$

$$x = 0.0007\ meters$$

$$velocity = 0.0007\ \frac{meters}{second}$$

Furthermore, the velocity is an important value that is useful in the calculation of the Reynolds number. The Reynolds number helps to categorize the type of flow. Reynolds values are categorized into laminar, transitional, or turbulent. Using the data found previously for the particle and pairing that with the kinematic viscosity of isopropyl alcohol, the Reynold's number of the particle I captured as it flowed across the isopropyl alcohol was approximately $17.5 \times 10^{-3}\ \frac{m^2}{sec}$. Since the Reynolds number is very small, the flow can be categorized as laminar. The following values were used in the Reynolds number calculation:

- velocity: u = 0.0007 $\frac{m}{s}$
- kinematic viscosity of isopropyl alcohol: $\nu = 2.8 \times 10^{-6}\ \frac{m^2}{sec}$
- distance moved: l = 0.0007 meters

$$Re = \frac{u \times l}{\nu}$$

$$Re = \frac{0.0007 \times 0.007}{2.8 \times 10^{-6}\ \frac{m^2}{sec}}$$

$$Re = 17.5 \times 10^{-2}$$

The technique I used for this assignment was the seeded boundary technique. We took our photos in a well lit room in the mechanical engineering department. We added an LED desk lamp afterwards because the phone camera blocked some of the light from above. One LED lamp was enough to make the fluid motion visible in our devices. Flash was not used in my video.

3 Photographic Technique

The field of view is 6.99 cm x 3.81 cm. The camera was 5.08 cm the whiteboard surface. The resolution of my phone camera was able to capture 1920 x 1080 pixels at 60 frames per second. Table 1 breaks down all the properties that I used to capture the video.

Table 1: Camera Properties

Property	Value
Camera Maker	Samsung
Camera Model	Galaxy S9
Frame Rate	60 fps
Resolution	1080p
Flash Mode	No Flash

Moreover, I used Adobe Premier to edit my video. I changed the colors to black and white. Using the cut feature, I cut out much of the video and only kept 55 seconds of original content. I added a sountrack called ghost dance by Kevin Mcleod. To match the fluid motion with the crescendos and decrescendos of the music, I stretched the 55 second video by ten percent.

4 Conclusion

In conclusion, the final video that I submitted shows the physics of fluid motion of ferrofluid in isopropyl alcohol that is affected by a moving magnetic field. I am pleased with the motion that I captured and the aesthetics of the video. I fulfilled my intention for this image, as I was able to capture fluid motion of ferrofluid. Moreover, having captured this motion, I am wondering what would happen if I mixed the isopropyl alcohol and the ferrofluid first before placing on the whiteboard surface. Future iterations can include the a comparison of the mixed and unmixed solution and the effect it has on the fluid motion

References

[1] Magcraft. *What is a ferrofluid?* Jan. 2015. URL: https://www.magcraft.com/blog/what-is-a-ferrofluid.

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