SOCIETY OF PHYSICS STUDENTS
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SPS Chapter Research Award Interim Report

Project Title	Shaping Analysis of Magnetic Ferrofluid
Name of School	William Jewell College
SPS Chapter Number	8235
Total Amount Awarded	$510
Project Leader	Denver Strong

Abstract

The William Jewell College Physics Department would like to examine shaping of ferrofluids in the presence of various magnetic fields and generate computer models of these shapes. Applications for on demand shaping include the disciplines of art, medicine, and engineering.

Statement of Activity

Interim Assessment

- Can computer modeling of ferrofluids in the presence of various magnetic fields predict shapes generated by ferrofluids interacting with magnetic fields in a laboratory? The backbone of this research project is to mathematically model the shape of magnetic fluids under one, two, and multi-pole domains. We plan to begin with an analysis of two magnets interacting with a fluid and progress to multiple electromagnets. This will develop the methods needed for users to predict and produce two and three-dimensional shapes, the latter being much more difficult. This proposed research will introduce a new area of experimental and computational research within our department.

- Attempts to model the fluid within a magnetic field has been disappointing throughout the semester. We have been trying to model the magnetic field in MatLab. We found an optimization equation which seemed promising from Park[1], but this only optimized the maximum point of the fluid. We are now looking at Jackson's Classical Electrodynamics[3] for more detailed equations of a magnetic field around an electromagnet. The computations and source code of the modeling should be sufficient for a publishable paper. There is an exceptionally long run time for any calculations as well. Many of the possible equations require summations so we would like to ask if we could redistribute some of the money into matlab programs that would allow us to handle these calculations quicker.*
- Park's[1] optimization equation incorporated density of the fluid, a key reason why we asked for the ferrofluid in the original proposal. If we could reallocate this money to MatLab programs that include parallel processing, we believe that it would be a much more efficient use of our time.
- The calculations themselves have held the project up a lot. Original computations assumed general electricity and magnetism knowledge could be used to solve the problem to pursue a more engineering based and applicable project, but the detail of graduate level equations is necessary for an acceptable model. Therefore, we are refocusing the project to stationary computations to produce an optimization equation across the entire relevant domain. This will be of much greater use to researchers and engineers who wish to apply this optimization technique to their own future work.
- This work has primarily been done with our Society of Physics Students Adviser, Dr. Blane Baker, and Denver Strong.
- With regards to the Society of Physics Students, the society is funding a new edge of research along with promoting research in small liberal arts colleges, such as our own. Although Denver is the only student working on the project, other students know what is being done and what can be done via SPS funding.
- *If this is possible, please email Denver Strong at strongd@william.jewell.edu

Updated Background for Proposed Project[2]

Ferrofluids, are systems composed of nanometer-sized magnetic particles suspended within a carrier fluid that allows the fluid to demonstrate magnetic properties when exposed to an external magnetic field. Ferrofluids are considered to be superparamagnetic substances being colloidal suspensions of nanoparticles. These fluids contain a carrier fluid and a surfactant which are typically organic compounds while solid magnetic particles are immersed in the carrier and surfactant mixture. The particles, typically magnetite or another particle with a similar crystalline structure, are magnetic nanoparticles. The surfactant is chemically composed of polar molecules where one end binds to the particle creating a coating around each particle preventing agglomeration and clumping. In ferrofluid, these particles are just large enough to contain a single magnetic domain. When there is no magnetic field present, the particles, as well as their magnetic domains, randomize creating a net magnetic field of approximately zero. When they are exposed to a magnetic field, though, the particles align themselves with the external magnetic field lines. This gives the fluid system a magnetic field itself and depending on the amount of fluid and the intensity of the field, what is known as spiking will occur in areas based from the surface instability. There is also a snaking effect which creates a divot in the fluid surface immediately surrounding the area of instability. One paper has appeared in the literature in the year 2010 describing the shaping of ferrofluids.[1] This paper only optimized the maximum point of the fluids shape disregarding the surface instability.

Description of Research - Methods, Design, and Procedures

Because this project has been developed over the course of a year, much of the observational components have been complete in discovering how the magnetic fluid acts in various magnetic fields. The majority of this semester has been specific to computation and modeling. Therefore, we have been continuously running various programs to get the correct optimization equations in MatLab. Once the program is complete, we compare the model to the actual shape of the magnetized fluid. Once we get an an accurate representation of the fluid while using one end of an electromagnet, we will move on to two poles. We should be able to sum the optimization constraints on each magnet to produce a shape over a flat surface. Afterwards, we will attempt to place magnets in three dimensions and produce acceptable models in 3D. Current issues reside in the speed of the program and the limited domain of the equations we are using.

Initial Results

Basic electricity and magnetism equations are not enough to effectively model the shaping of magnetic fluid within a magnetic field. We have currently been looking at Jackson's Classical Electrodynamics[3] book for more sophisticated equations.

Matlab is not incredibly efficient when running excessive computations in a single serial script. We are trying to develop ways to increase the speed while not losing resolution of the graph or the script's readability.

Statement of Next Steps

Plan for Carrying Out Remainder of Project (including Timeline)

Timeline

- August: Complete Understanding of electricity and magnetism equations
- September: Two-dimensional implementation of an accurate model. This would include multiple electromagnets in the xy-plane with fluid along the z-axis
- November: Three-dimensional implementation of the model with electromagnets and magnetic fluid in the xyz coordinate system.

Personnel

- Denver Strong will be the only student contributing to the project under the advisement of Dr. Blane Baker. The small size of William Jewell's physics department did not allow us to get more members on the project. Dr. Patrick Bunton is also a fluid mechanics expert available for reference.

Bibliography

[1] Equilibrium shapes of ferrofluid under different forces using continuum shape sensitivity analysis and level set method, Y.S. Kim, I.H. Park, Journal of Applied Physics 9, 107 (2010)

[2] Ferrofluids: Properties and Applications, C. Scherer and A.M.F. Neto, Brazilian Journal of Physics Braz. J. Phys. 35, 718 (2005).