Electrorheological Fluids - Theory and Experiments

Summer 2007 REU Project Summary

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Electrorheological (ER) fluids are a unique class of materials. An ER fluid is a suspension at its most basic level. ER fluids consist of a polymeric liquid, usually an oil, with small spheres (typically glass or metal) added to the liquid. As this combination is then mixed into a slurry-like substance, very interesting properties become evident.

In this suspended state, ER fluids exhibit a drastic change in viscosity when exposed to a sufficiently strong electric field. This change in viscosity may be on the order of 100,000 and typically occurs within 5-10 milliseconds. The large change in viscosity essentially allows the ER fluid to transform from a material possessing primarily liquid characteristics to a material possessing primarily solid characteristics almost instantaneously.

The exact mechanisms causing this drastic change in characteristics are not fully understood presently. Many ideas have been formulated and seem to partially fit the empirical evidence, but there is a large need for further research and understanding. It is this need that we have set out to meet in our research project.

Our goal in this project has two parts: first, to study the theoretical principles of ER fluids. Second, we plan to design and build a small-scale model of an ER fluid. By coupling theoretical understanding with the experimental insight that may be gained from a small-scale model, we have anticipated gaining a greater understanding of ER fluid mechanisms and behavior. We hope that this project will not only bring a more thorough understanding of ER fluid theory, but also tangible results in the forms of empirical data and test equipment.

THEORETICAL LEARNING

I first began gaining a better understanding of ER fluid theory by reading various journals, papers, and books related to our research focus. Particularly insightful were the proceedings from the annual International Conference on Electro-Rheological Fluids and Magneto-Rheological Suspensions. These volumes helped me to understand recent research related to ER fluids.

A great item of interest found in these proceedings was theory relating ER fluid behavior based on statistical mechanics. Dr. Golden and I have found the area of statistical mechanics to be a very useful theory in explaining the behavior of ER fluids. As an electric voltage is applied to an ER fluid, the spheres begin to display dipole movement. These charged particles then start to align into chains according to the induced dipoles. As groups of chains link together, columns are eventually formed. Statistical mechanics may offer some explanation as to the probability of chain formation and location. We plan to explore this theory further as it relates to ER fluids.

I have also read large parts of *Introduction to Percolation Theory*, by Dietrich Stauffer. Percolation theory is an area of great interest in our study of ER fluids. We have noticed a number of similarities between percolation principles and ER fluid chain formation. The concept of cluster formation is essential to understanding percolation theory. This same idea of cluster formation may well serve to explain the conglomeration and formation of chains within ER fluids. We plan to explore the idea that there may be some critical value or critical exponent that influences the transport of particles within the ER fluid. To our knowledge, no such analysis has yet been performed by ER fluid researchers to predict the behavior of ER fluids. We eagerly anticipate further investigation into this theoretical connection with the availability of empirical data.

MODEL DESIGN

As the foundation of theoretical knowledge has been laid, the process of designing and building a small-scale model of an ER fluid has taken a more solid form. As discussed previously, a small-scale model would be invaluable in the study of ER fluids. With a model, different variables can be changed and the corresponding effects studied. Data will be possible to gather, allowing theories such as statistical mechanics and percolation theory to be more fully explored.

We have approached the task of designing this model scientifically. As this research project spans the border between applied mathematics and engineering, we have drawn upon engineering principles and guidelines to compliment the mathematical theory.

The first task in the model design was to define criteria for our small-scale model. After much discussion and thought, Dr. Golden and I have determined a few key elements that must be found in our model. First, it must be safe (high electric voltages will be present). The model must allow for the viewing and photographing of ER fluid chains as they form. We would like the model to be easily disassembled to allow for the variation of polymer liquids and different types of spheres.

As different options have been discussed, we have found a valuable consultant in Dr. Weijia Wen of the Hong Kong University of Science and Technology. Dr. Wen is one of the world's foremost leaders in ER fluid research. Dr. Wen has been in constant contact via email and telephone, offering insightful suggestions and recommendations for our model.

We are presently planning to construct the model out of an acrylic plastic. Such plastics are easily machined and adhere well to sealants and adhesives. This will allow the joints of the viewing area to be sealed while still leaving the option available to change fluids within the model. An acrylic plastic will not greatly distort light waves as they travel through the medium, giving us an image of ER chains with low levels of distortion.

The largest challenge we are facing is supplying the voltage necessary to create chains in the ER fluid. Chains will begin to form around 400 volts/mm, with columns being induced around 1000 volts/mm. Care must also be taken not to approach the breakdown voltage of air, which is roughly 3000 volts/mm. If the breakdown voltage of air is approached, unpredictable and dangerous arcing can occur in the system. As a result, we must stay under the breakdown voltage of by a factor of safety. Thus we would like to create an electric field of at about 500 volts/mm within our model. If we include a 6mm gap between the electrodes, we will need to supply 3000 volts. We are currently exploring different power supplies and signal generators that we can safely utilize to create this voltage. We also are working with Prof. Arn Stolp of the Electrical and Computer Engineering Department at the University of Utah to design a safe method for integrating the power supply into the model.

Sphere selection is also another ongoing process. Typical sphere sizes within an ER fluid generally range from 5 micrometers to 50 micrometers. Sphere materials can vary between glass and metal. Initially we plan to use glass spheres within our model. We currently are in communication with two different distributors that may potentially be able to provide the spheres that we are seeking. ER fluids tend to exhibit a response more readily with a smaller sphere size. Consequently, we are planning to start with spheres that are about 10-15 micrometers in diameter. The aforementioned distributors are currently reviewing their products to ensure that they can provide spheres in the sizes we desire. We expect to hear back from them in the coming weeks.

After we have finalized the general layout and design of the experimental equipment, we then plan to create a 3D model of the design. The 3D model will be created in an appropriate software package (such as Pro-E or SolidEdge). We plan to create this 3D model to aid in the future production of additional small-scale models. A 3D model of the experimental equipment would allow a machinist to quickly produce the necessary parts and make assembly much more simple. A 3D model would also allow us to easily share our design with other groups when necessary. We hope to have the design finalized within the next month, allowing us to then produce the 3D model.

After the small-scale model is constructed, we plan to research the effect of altering variables within the suspension. We hope to particularly explore a very interesting phenomenon that occurs in a special type of ER fluid setup. This special case requires that metal spheres be used in the suspension instead of glass spheres. It also requires that the chamber where chain formation occurs be round, extending radially from a center electrode to a larger outer electrode ring on the edge of a circle. When such a setup is introduced to voltage, the columns form in fractal-like patterns, extending from the center electrode. This same type of fractal pattern is found in other percolation-based models, such as sea ice. We hope to gain a better insight into this mechanism and offer an explanation of the fractal formation.

CONCLUSION

As detailed above, Dr. Golden and I have made great strides in our research goals. We have gained a much better theoretical understanding of ER fluids to ace as a basis for designing a small-scale model. We have begun to layout our model and have been made aware of special issues that must be addressed in this model.

As we continue this project, we plan to finalize our experimental layout with a 3D model. We then plan to begin the actual construction of the small-scale model. As explained above, the small-scale model will greatly enhance our ability to study and explain behavior in ER fluids.

Currently there is great interest in ER fluids from many groups in industry, driving ER fluid research. For example, these materials may be used in automotive applications for active suspensions or military applications for personal defense systems, with countless other uses possible. We look forward to studying ER fluids further, allowing us to contribute to the theory explaining these important materials.