STUDY OF FERROFLUIDS

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ABSTRACT

Ferrofluids are a special subdivision of magnetic fluids that consist of dispersed magnetic nanoparticles in a non-magnetic liquid carrier and are stabilized by the addition of a surfactant monolayer onto the nanoparticles. Ferrofluid was invented by a NASA engineer by the name of Steve Papell in 1964 to make sure that fuel which may settle or disperse inside the fuel tank can be pumped into the combustion chamber, where he suspends finely ground iron oxide into the rocket fuel.

Ferrofluids are colloidal fluids consisting nanoscale ferromagnetic or ferrimagnetic particles suspended in a transporter liquid where each nanoparticle of the magnetic substance is completely encompassed by a surfactant to resist clustering due to intermolecular forces as well as magnetic forces.

The difference between magnetorheological (MR) liquids is the difference in the size of the particles where the particles in the ferrofluid are nanoparticles which are suspended by Brownian movement and are stable hence will not settle under standard conditions. Whereas the magnetorheological consist of micrometre scale particles which settle after a certain period of time as the Brownian motion does not apply due to the
size of the particles.

TIMELINE

Selection of topic and initial research	REVIEW 1
Implementation by synthesis and experimentation	REVIEW 2
Compilation and Report formation	REVIEW 3

WORK DISTRIBUTION

Review 1 PPT: Immanuel Varghese Koshy, Sruthi Maria Jayachandran, Tarun Raghav PR, Anshita Bala

Review 1 presentation: Immanuel Varghese Koshy

Review 2 PPT: Sruthi Maria Jayachandran, Immanuel Varghese Koshy

Review 2 presentation: Immanuel Varghese Koshy

Research paper: Deepshikha GopiNath, Sruthi Maria Jayachandran, Sabyasachi Mohanty, Tarun Raghav PR, Immanuel Varghese Koshy, Anshita Bala, Riya Soni Jacob

Procuring materials: Deepshikha GopiNath, Tarun Raghav PR, Sabyasachi Mohanty

Review 3: Immanuel Varghese Koshy

INTRODUCTION

Ferrofluids are manufactured by dispersing colloidal ferromagnetic, single domain nanoparticles into a non-magnetic liquid carrier that encompasses every individual nanoparticle to keep it stable instead of clumping together due to wonder Waals forces and is achieved by the Brownian movement of the ferromagnetic or ferrimagnetic nanoparticles.The particles in ferrofluids are scattered in a fluid, frequently utilizing a surfactant, and accordingly ferrofluids are colloidal suspensions – materials with properties of in excess of one condition of issue. For this situation, the two conditions of issue are the strong metal and fluid it is in. This capacity to change stages with the utilization of an attractive field enables them to be utilized as seals, greases, and may open up encourage applications in future nanoelectromechanical frameworks.

Real ferrofluids are stable. This means that strong particles do not mix or disintegrate even in the most dynamic environment. In any case, the surfactant tends to disintegrate over time (a few years), and eventually the Nano-particles will combine, and will disintegrate and will no longer add to the attractive reaction of the liquid.

Ferrofluids represent a special class of magnetic fluids and are manufactured fluids consisting of dispersions of magnetised nanoparticles in a variety of non-magnetic liquid carriers. They are stabilized against agglomeration by the addition of a surfactant monolayer onto the particles

The term magnetorheological fluid (MRF) refers to liquids similar to ferrofluids (FF) that solidify in the presence of a magnetic field. Magnetorheological fluids have micrometre scale magnetic particles that are one to three orders of magnitude larger than those of ferrofluids.However, ferrofluids lose their magnetic properties at sufficiently high temperatures, known as the Curie temperature.

Ferrofluids are manufactured by Steve Papell ,working under The National Aeronautics and Space Administration research centre in 1964 while they were researching methods of controlling liquids in a zero-gravity environment where magnetic fields could control the location of a ferrofluid. The name ferrofluid was introduced, the process improved, more highly magnetic liquids synthesized, additional carrier liquids discovered, and the physical chemistry elucidated by R. E. Rosensweig and colleagues. In addition Rosensweig evolved a new branch of fluid mechanics termed ferrohydrodynamics which sparked further theoretical research on intriguing physical phenomena in ferrofluids

PROPERTIES:

- Particle measure: If molecule is too extensive then it responds freely with the attractive field.
- Coating of nanoparticles: Without the covering of a surfactant the attractive field will pull the molecule out of the attractive field.

Ferrofluids have a large number of applications like rotary seals in hard drives, rotating shaft motors, in loudspeakers to dampen vibrations as well as a contrast agent for MRI’. One of the major benefits of ferrofluid is that liquid can be forced to flow via the positioning and strength of the magnetic field and so the ferrofluid can be positioned very exactly .They also have the capability of reducing friction, making them useful in variety of electronic and transportation applications.

MATERIALS REQUIRED

To incorporate a ferrofluid, we require the accompanying materials:

1. Magnets
2. Motor oil
3. Ferric powder (67.8 conc)
4. Mixing apparatus

METHODOLOGY

There are two important steps in making ferrofluids:

1) amalgamation of the attractive strong, magnetite
2) suspension in water with the guide of a surfactant.

The surfactant utilized as a part of this union is usually tetramethylammonium hydroxide ($N(CH_3)_4OH$).

$2FeCl_3 + FeCl_2 + 8NH_3 + 4H_2O \rightarrow Fe_3O_4 + 8NH_4Cl$

- Take some of the ferric oxide powder in a beaker
- Pour 30 ml of motor oil to it { for 50 ml of ferric oxide, we use 30 ml of oil}
- Stirring into nice consistency
- Touch a magnet to the base of the container
- Contouring shapes occur based on the strength of magnet

OBSERVATION

First we used almond oil to observe the patterns formed, some of them are below:

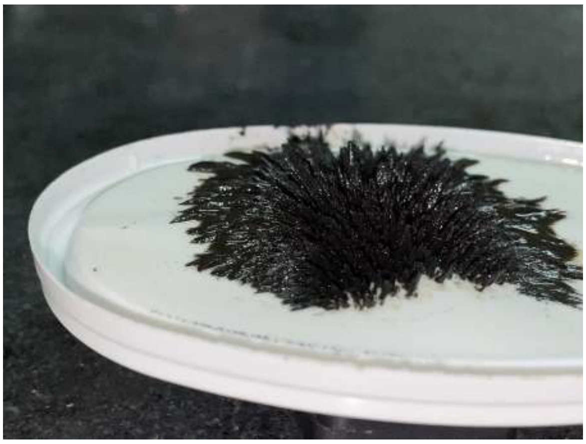
 

Later when we switched to motor oil , the following was observed:








OBSTACLES WHILE DOING THE PROJECT

1. The particles should be rather tiny.If they're big enough, they'll be able to behave freely in the appealing field.
2. The ferrofluid should be thoroughly coated with a surfactant, otherwise the iron oxide particles would act independently and separate from the solution.
3. Due to the change from internet to offline sourcing, finding various types of magnets was difficult.
4. Sourcing the iron particles was fairly easy but getting them through the airport authorities was hard, resulting in a delay in sending them to campus,and in turn late review and the labs had broken equipment.

APPLICATIONS

Most applications of magnetic fluid are based on the following of its properties:

1) It goes to where the magnetic field is strongest and stays there

2) It absorbs electromagnetic energy at convenient frequencies and heats up;

3) Its physical properties may change with the application of a magnetic field;

These properties make the magnetic fluids useful for many technological, biological and medical purposes, as well as a help in materials science and engineering research. In the following sub-sections we comment on some of these applications.

A. Technological Applications

Of the many technological applications of magnetic fluids we will single out four main categories:

a) Dynamic sealing

In many equipments there are two or more different ambients, which have to be hermetically isolated from each other but some shaft has to carry energy (rotation) from one ambient into the other. For example, a motor has to be in an open place, where it can be cooled down by the ambient air or some refrigeration mechanism, while a shaft has to go from it into an absolutely clean place, where it has to rotate something. This is the case, for example, of the hard disks of computers, which have to operate in an hermetically closed box because any grain of powder or even smoke may spoil the reading and writing process. Therefore it is necessary to seal hermetically the hole through which the axle passes. This is achieved by making the hole inside a magnet and the shaft made of soft magnetic material. A groove in the shaft is filled up with ferrofluid, which is kept in place by the magnetic field, obstructing the passage of any impurity, but leaving the axle free to rotate, because the obstructing material is liquid.

b) Heat dissipation

One way of extracting heat from an equipment which heats up by functioning, and so keeping it not too hot, is by using a good heat conductor which connects the equipment to some mass which has much bigger heat capacity and, perhaps, much bigger open surface to dissipate heat. In some cases the good heat conductor must not be a solid, because it would block the equipment's operation (for example, if it has to vibrate). One way to achieve the desired goal is by using a ferrofluid as heat conductor. A non magnetic liquid would flow away from the place where it is supposed to operate. A good example is a loudspeaker, whose coil heats up by functioning and the ferrofluid is kept in place by the magnetic field of the magnet which is fixed on the loudspeaker's horn. Nowadays most of the high power loudspeakers are equipped with ferrofluid. The presence of the fluid around the coil improves also the quality of the speaker because it damps unwanted resonances, which would produce a very unpleasant noise.

c) Damping

We mentioned above that magnetic fluids are used also as dampers in loudspeakers. A more direct use for damping unwanted vibrations is associated to their use as inertial and viscous dampers for motors, mainly stepper motors. For this purpose use is made of the unique property of magnetic fluids that can keep a magnet, whose mass density is bigger than that of the fluid, floating in it, with part of its volume above the liquid's surface. This is because the magnetic field gradient pulls the magnetic fluid to the region under the immersed pole of the magnet, causing a pressure (magnetic pressure) which pushes the magnet up. The equilibrium is established when the magnet's weight is counterbalanced by this magnetic pressure and the hydrostatic pressure. Even a non-magnetic body can "levitate" if there is a magnetic field gradient applied on the ferrofluid, which causes a magnetic pressure gradient in the fluid. A stepper motor operated at its natural frequency may experience excessive settling time, vibration and acoustic noise. A damper absorbs the unwanted vibration by a shearing effect which produces a torque that opposes the oscillatory motion. The damper has a non-magnetic housing which attaches to the motor shaft. Inside the housing is an inertial mass which levitates on ferrofluid, thus eliminating the need for bearings to support the mass

B. Materials research

Of the several possibilities of use of ferrofluids as a help on the study of materials, we have chosen to describe only the case of liquid crystals doping, which is made in one of our laboratories.

1. Magnetic colloids used to dope liquid crystals

The use of magnetic colloids to dope liquid crystals was proposed by Brochard and de Gennes in a seminal paper in 1970. They proposed to introduce anisotropic magnetic nanoparticles ($L/d \sim 10$, where L and d are the length and the diameter of the cylindrical particles) in a liquid crystalline matrix. This doping should reduce by a factor of 10^3 the magnetic field necessary to orient liquid crystals.

According to experimental observations with lyotropic nematic liquid crystals, above a minimum value of the concentration of particles, c_m, the liquid crystalline matrix collectively follows the orientation of the magnetic particles. Rault and co-workers observed, for the first time, this macroscopic collective behavior in a nematic liquid crystal doped with magnetic microparticles (typical size larger than that of actual ferrofluids). This minimum concentration was shown to be $c_m \sim 1/()$, where D_s is the thickness of the sample.

The doping of lyotropic liquid crystals with water-based surfacted ferrofluids was achieved in 1979 by Liébert and Martinet. After that, this procedure was widely used to investigate different aspects of the physics of liquid crystals. Magnetic nanoparticles can be used to investigate dynamic processes in lyotropic ferronematics (nematic liquid crystals doped with ferrofluids), in particular the response of the nematic matrix to pulsed magnetic fields.

2. Doping of lyotropic liquid crystals with magnetic particles

Ferronematic and ferrocholesteric lyotropic liquid crystals were prepared for the first time by Liébert and Martinet mixing a water-based surfacted ferrofluid (Fe_3O_4 grains, with a mean diameter of 15.4 *nm*) with lyotropic nematic and cholesteric mixtures. The collective behavior of the liquid crystalline matrices was observed with magnetic fields of about 20 *G*. The use of ferrofluids to orient lyotropics was essential in experiments in which the reciprocal structure of the biaxial nematic phase was determined.

The ferrofluid doping of nematic liquid crystals can be used to investigate elastic properties of liquid crystals. In particular, the bend elastic constant, k_{33}, and the anisotropy of the diamagnetic susceptibility, c_a can be measured by comparing the relaxation behavior of these complex fluids (liquid crystals with and without the ferrofluid doping) when subjected to different magnetic fields.

The controversial subject of the effective splay-bend elastic constant, k_{13}, was also investigated using ferrofluid doped lyotropic samples. The ratio between k_{13} and the usual Frank elastic constant found in the potassium laurate/decanol/water lyotropic mixture was positive and of the order of 1.

C. Biomedical Applications

In Biomedical applications one can also single out some main categories:

a) Magnetic drug targeting

Localizability of a portion of ferrofluid by a magnetic field, associated with the fact that any liquid may be turned into a magnetic fluid, offers very interesting applicability in medicine. Much attention has been done to bounding on ferrofluids chemical drugs appropriate for chemotherapy. The idea is: such a ferrofluid bounded drug is injected in a cancer tumor and there it is kept during some time (» one hour) by a suitably focused magnetic field, where it has a very intense action. The amount of drug necessary is much less than what would be necessary if it were dispersed in the whole body. When the magnetic field is turned off the drug will disperse in the body, but, since the total amount is very small, there will be practically no side effects. A paper by Lübbe *et.al.*presents a wide variety of possibilities with this technique and offers a detailed classification of the treatments along these lines. In a more recent paper, Alexiou *et.al.* report on application of ferrofluid bound Mitoxantrone in 26 tumor-bearing rabbits, showing absolute success in healing the tumor, without side effects.

b) Hyperthermia

The property of ferrofluids of absorbing electromagnetic energy at a frequency that is different from the frequency at which water absorbs energy allows one to heat up a localized portion of a living body, where ferrofluid has been injected, for example a tumor, without heating at the same time the surrounding parts of the body. A number of experiments, healing cancer tumors in rats and rabbits by this technique have been reported during the last few years. In the year of 2004 a new important step was given in this direction: humans have had their cancer tumors successfully treated by magnetic fluid hyperthermia (MFH). A work entitled "Magnetic fluid hyperthermia (MFH): A new therapeutic option in the treatment of glioblastomas (GB)" was recently presented in the "55º Jahrestagung der Deutschen Gesellschaft für Neurochirurgie e.V. (DGNC)", in Köln. An experimental treatment of 15 patients, in association with a low dose radiotherapy, showed very good results; the treatment was well tolerated by the patients, leaving clear that it constitutes an important new weapon against cancer.

c) Contrast enhancement for Magnetic Resonance Imaging – MRI

MRI has been one of the most powerful diagnosis techniques used in medicine in recent years. Its ability to distinguish between different tissues relies on the different relaxation times T_2 of the proton's magnetic moments when it is inside different ambients. Frequently, however, the differences are not strong enough to render well resolved images. If magnetic particles from a biocompatible ferrofluid are selectively absorbed by some kind of tissue, this will become very clearly visible by MRI. Moreover, different tissues uptake different amounts of the magnetic particles, having, therefore, different values of T_2 and distinguishable images. Dextran coated iron oxides are biocompatible and are excreted via the liver after the treatment. They are selectively taken up by the reticuloendothelial system. This is important because tumor cells do not have the effective reticuloendothelial system of healthy cells, so that their relaxation time is not altered by the contrast agent, which makes them distinguishable from the surrounding healthy cells. Pankhurst *et.al.*, in a recent topical review on applications of magnetic nanoparticles in biomedicine, have listed a number of situations where the technique of MRI with ferrofluid contrast has been used with good results.

d) Magnetic separation of cells.

It is often advantageous to separate out specific biological entities from their native environment, for different possible reasons: to produce concentrated samples of these entities or to freed an infected sample from them. Magnetic separation using biocompatible magnetic particles from ferrofluids is one way to achieve this. It is a two-step process: 1) fixing a magnetic particle to the desired biological entity, and 2) pulling the magnetic particles, together with their "prey" out of the native environment by the action of a magnetic field gradient. Fixing the magnetic particle to the biological entity is made possible by coating the particle with an appropriate material, such as dextran, polyvinyl alcohol and others.

Uses of cell separation include clean up bone marrow from cancer infected samples taken from a person, aiming to use the purified samples to be implanted again in the same person, avoiding in this way the rejection, very common when the implanted material comes from a different donor. In this case, magnetic nanospheres are coated with monoclonal antibodies having an affinity for the tumor cells. When marrow removed from the patient is put in contact with the coated spheres in a liquid solution, the tumor cells selectively attach to the surface of the spheres, which are then magnetically separated from the solution.

CONCLUSION

The project was a very new topic to each one of us. First we tried using almond oil and was able to make a Ferrofluid but the surfactant properties of almond oil was not sufficient. Therefore we used motor oil which by nature of its chemical composition is an excellent surfactant and help us achieve proper ferrofluid state

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