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Ferro Fluids: - Properties and Applications

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Abstract:

Magnetic fluids may be classified as ferrofluids which are colloidal suspensions of very fine (» 10 nm) magnetic particles.

We review the general classification and the main properties of , some theoretical models and a few applications. We consider the stability of a in terms of various forces and torques on the magnetic particles.

A large portion of this review is dedicated to applications of , including a few of the many technological applications. Among the uses of a in the study of materials, we have selected the doping of liquid crystals. Among the very promising uses in Medicine, we discuss drug targeting, hyperthermia, cell separation, and contrast in magnetic resonance imaging.

INTRODUCTION

A ferro-fluid is a liquid that becomes strongly magnetized in the presence of a magnetic field. Ferrofluid was invented in 1963 by NASA's Steve Papell as a liquid rocket fuel that could be drawn toward a pump inlet in a weightless environment by applying a magnetic field.

Ferro fluids are colloidal liquids made of nanoscale ferromagnetic, or ferromagnetic, particles suspended in a carrier fluid (usually an organic solvent or water.The tiny magnetic particles are coated with surfactant to prevent agglomeration and being ripped off

from the homogenuse colloidal mixture under the influence of magnetic force. The surfactants Vander Waals forces are sufficient to prevent magnetic clumping of nanoparticles with weak magnetic field. Ferro-fluids usually do not retain magnetization in the absence of an externally applied field and thus are often classified as "super-paramagnets" rather than ferromagnets.

DESCRIPTION

Ferro fluids are composed of nanoscale particles (diameter usually 10 nano meters or less) of magnetite, hematite or some other compound containing iron. This is small enough for thermal agitation to disperse them evenly within a carrier fluid, and for them to contribute to the. The composition of a typical ferrofluid is about 5% magnetic solids, 10% surfactant and 85% carrier, by volume.

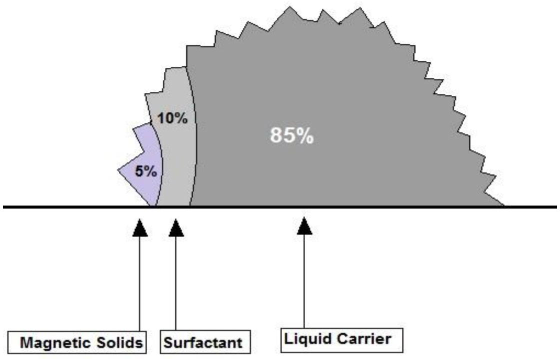

fig. Constituents of ferro-fluids

Particles in ferrofluids are dispersed in a liquid, often using a surfactant, and thus ferrofluids are colloidal suspensions – materials with properties of more than one state of matter. True ferrofluids are stable. This means that the solid particles do not agglomerate or phase separate even in extremely strong magnetic fields. However, the surfactant tends to break down over time (a few years), and eventually the nano-particles will agglomerate, and they will separate out and no longer contribute to the fluid's magnetic response.

The term magnetorheological fluid refers to liquids similar to ferrofluids 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. Ferro fluids lose their magnetic properties at sufficiently high temperatures, known as the Curie temperature.

Normal-field_instability

The paramagnetic fluid is subjected to a strong vertical magnetic field, the surface forms an even pattern of peaks and valleys. This effect is known as the *normal-field instability*. The instability is driven by the magnetic field; it can be explained by considering which shape of the fluid minimizes the total energy of the system.

Peaks and valleys are energetically favorable in the corrugated configuration, the magnetic field is concentrated in the peaks; since the fluid is more easily magnetized than the air, and this lowers the magnetic energy at the time of formation of peaks and valleys and is resisted by gravity and surface tension. It costs energy to move fluid out of the valleys and up into the spikes that costs energy to increase the surface area of the fluid. Hence, the formation of the corrugations increases the surface free energy and the gravitational energy of the liquid, but reduces the magnetic energy. The corrugations will only form above a critical magnetic field strength, when the reduction in magnetic energy outweighs the increase in surface and gravitation energy terms.

Ferrofluids have an exceptionally high magnetic susceptibility and the critical magnetic field for the onset of the corrugations can be realized by a small bar magnet.

Common ferrofluid surfactants

The surfactants used to coat the nanoparticles include, but are not limited to:

1. oleic acid
2. tetramethylamonium hydroxide
3. citric acid
4. soy lecithin

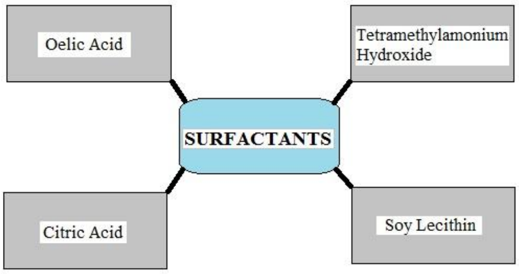

Fig. Surfactants

These surfactants prevent the nanoparticles from clumping together, ensuring that particles do not form aggregates that become too heavy to be held in suspension by Brownian motion. The magnetic particles in an ideal ferrofluid do not settle out, even when exposed to a strong magnetic or gravitational field. A surfactant has a polar head and non-polar tail (or vice versa), one of which adsorbs to a nanoparticle, while the non-polar tail (or polar head) sticks out into the carrier medium, forming an inverse or regular micelle, respectively, around the particle. Electrostatic repulsion then prevents agglomeration of the particles.

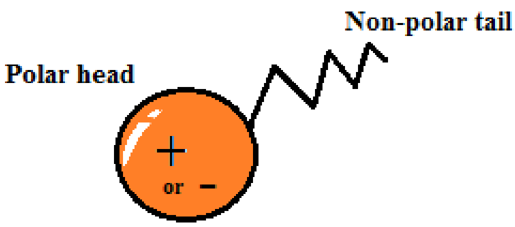

Fig. Ferro-fluid Molecule

While surfactants are useful in prolonging the settling rate in ferrofluids, they also prove detrimental to the fluid's magnetic properties. The addition of surfactants or any other foreign particles decreases the packing density of the ferroparticles, thus decreasing the fluid's on-state viscosity, resulting in a “softer" activated fluid. While the on-state viscosity is less of a concern for some ferrofluid applications, it is a primary fluid property for the majority of their commercial and industrial applications and therefore a compromise must be met when considering on-state viscosity versus the settling rate of a ferrofluid.

SELECTION OF FERROFLUID

The selection of ferrofluid depends on the factors like environments, operating life, characteristics, etc.

Example: - Fluorocarbon based ferrofluids are selected as thermal insulators because of their lowest thermal conductivity.

Ferrofluids come in contact with a wide variety of materials, hostile gases, various adhesives, plastics and plating materials. Therefore ferrofluids must be chemically compatible with these materials. The ferrofluid is carefully selected to meet application requirements.

APPLICATIONS

1. Bio-Medical Ferro fluids

Current research in the area of medical requires magnetic nanoparticles. Ferromagnetic materials is combined with a liquid monomer to create a polymer with magnetic properties which can be shaped into micro-beads which are coated with antibodies, DNA or other biologically active material and then used in the diagnostic process.

Solutions containing magnetic particles are injected into a body, then using powerful electromagnets they are guided to the site of a tumor where the magnetic field is increased, to create a strong excitation of the particles which creates a great deal of heat, and raise the internal temperature of the tumor, killing the targeted cells while doing little or no damage to surrounding tissues.

2. Material Separation and Recycling

Apparent density of the ferrofluids can be increased by applying a magnetic field to the ferrofluid which creates the ability to separate objects of different density through floatation or sinking but with limited economic advantage.

3. Electrical Transformers

Ferrofluids shows both thermal and dielectric benefits to transformers. Ferrofluid can be utilized to improve cooling by enhancing fluid circulation within transformer windings. Ferrofluid can also be applied to increase transformer capacity to withstand lightning impulses. Using ferrofluid we can design smaller, more efficient transformers, or extend the life or loading capability of existing one.

4. Quiet Solenoids

The use ferrofluid into a solenoid reduces the noise level of certain machines, such as kidney dialysis machines. This in turn reduces the need for noise suppression insulation and also the ferrofluid-based solenoids make the equipment more reliable.

5. Sensors & Switches

The use of ferrofluid may enhance the motion sensitivity of some sensors including inclinometers, accelerometers and flow meters, tilt, vibration, pressure and level sensors, and various switches.

6. Domain Detection

Ferrofluids are used for the study of magnetic domain structures in magnetic tapes, floppy disks, magneto-optical disks, crystalline or amorphous alloys, steels and geological rocks.

Ferrofluid is applied to the magnetic tape, disk or other specimen so that a thin layer of ferrofluid covers the surface. When the liquid evaporates, the particles congregate at the domain boundaries which appear as the dark lines in light and can be viewed with a microscope. A small external magnetic field is applied to the specimen to enhance the contrast of the pattern.

7. Ferro fluidic Seals

Ferrofluids in the form liquid is used as seals around the spinning shafts in hard disks. The rotating shaft is surrounded by magnets so that the ferrofluid is held in place due to magnetic attraction.

The ferrofluids acts as a barrier which prevents debris from entering inside the hard drives.

8. Spacecraft Propulsion

Ferrofluids can be made to self-assemble nanometer-scale needle-like sharp tips under the influence of a magnetic field which when reaching a critical thinness begin emitting jets that might be used in the future as a thruster mechanism to propel small satellites.

9. Analytical Instrumentation

Ferrofluids have many optical applications because of their refractive properties which include measuring specific viscosity of a liquid placed between a polarizer and an analyzer, illuminated by a helium–neon laser.

Other Applications

Ferrofluids are used as a friction reducing agent in different machines.

Ferofluid emulsion can be used to build optical filters tunable for different wavelengths by varying the magnetic field.

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