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APPLICATIONS OF MAGNETIC FLUID A REVIEW

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Abstract-*Magnetic fluid or the Ferrofluid is a very impressive fluid, due to the properties they possess. The magnetic fluid was invented long before but its applications started immerging during nineties. In recent years their applications in medical field is immerged and a vast area of their applications is opened. Number of the most important and recent applications of ferrofluid or magnetic fluid in Engineering and Medical field are discussed in this review paper.*

Keywords- *Ferrofluid or Magnetic fluid.*

I. INTRODUCTION

A magnetic fluid is a magnetic colloid sometimes called as a ferrofluid. It is a colloidal suspension of single-domain particles having magnetic properties, with typical dimensions of about 2 to 15 nm, dispersed in a liquid carrier [1–3]. The liquid carrier may have polar or nonpolar nature. Applications of these material - fluid is still increasing in numbers as well as in different fields since their inception. Ferrofluids are different from the usual magnetorheological fluids which are used for dampers, brakes and clutches, formed by micron sized particles dispersed in oil. In magnetorheological fluids when a magnetic field is applied, viscosity increases enormously. Due to this for strong enough fields, they may behave like a solid. While a ferrofluid keeps its fluidity even if subjected to strong magnetic fields.

Ferrofluids are isotropic in normal conditions but, when an external magnetic field is applied, they exhibit induced birefringence [4]. Wetting of particular substrates can also induce birefringence in thin ferrofluid layers [5].

In order to avoid agglomeration, the magnetic particles have to be coated with a shell of an appropriate material. Depending upon the coating, the ferrofluid's are classified as surfacted ferrofluid when the coating is a surfactant molecule or ionic ferrofluid when electric shell.

There are two methods to prepare these nanoparticles, by size reduction [1] and chemical precipitation [6]. In size reduction, magnetic powder of micron size is mixed with a solvent and a dispersant in a ball mill in order to grind for a period of several weeks. Now a days chemical precipitation is mostly used method to prepare magnetic nanoparticles. Different procedures have been developed to achieve this goal. These procedures start with a mixture of $FeCl_2$ and $FeCl_3$ and water. Co-precipitation occurs with the addition of ammonium hydroxide, and then the system is subjected to different procedures to peptization, magnetic separation, filtration and finally dilution. Surfacted ferrofluids are widely used in technological devices, being commercially available [8][9].

II. APPLICATIONS OF FERROFLUIDS

Ferrofluids or magnetic fluids are widely used in the field. There are many applications of ferrofluid in engineering and medical field. Magnetism has application in numerous fields like diagnostics, drug targeting, molecular biology, cell isolation, cell purification, hyperthermia, and radioimmunoassay[24]. Drug targeting is the delivery of drugs to receptors or organ or any other specific part of the body to which delivery of the drug is required. Different nonmagnetic microcarries like nanoparticles, microspheres and microparticles are utilized for drug targeting but they show poor site specificity and are rapidly cleared off by reticuloendothelial system under normal circumstances[23]. Ferrofluid is widely used to deliver the drug at the specific part of the organ with the help of external magnetic fiel[23]. Ferrofluid play an important role in this case, magnetic particles composed of magnetite which is well tolerated by the body, and magnetic fields are believed to be harmless to biological systems and adaptable to any part of the body. Up to 60% of an injected dose can be deposited and released in a controlled manner in selected non reticuloendothelial organs. Ferrofluid carriers were developed to overcome two major problems encountered in drug targeting namely reticuloendothelial system clearance and target site specificity[23].

In recent time the magnetic fluid has found its way in the medical field as well. Way back NASA used magnetic fluid in its space craft and satellites. Science long it is used in the field of mechanical engineering some of them are discussed in little detail.

A. Dynamic Sealing

In many types of equipment there are two or more different parts, required to be hermetically isolated from each other but some shaft has to carry rotational energy from one ambient into the other. A motor has to be placed in an open place, where it is needed to be cooled down by the ambient air or some other cooling mechanism, while a shaft has to go from it into an absolutely clean place, where it has to rotate load.

In 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

The best way of removing heat from heat generating equipment which heats up due to its functioning, and required to be kept at low temperature, is to use a good heat conductor which connects the equipment to heat sink with high mass which has higher heat dissipating capacity due to large mass and surface area. Sometimes it is required that this good heat conductor is liquid as the solid one may obstruct the functioning of the equipment.

Ferrofluid is the solution to this problem. Ferrofluid can be used as heat conductor. Ferrofluid will not would flow away from the place where it is supposed to stay and operate due to proper application of the magnetic field. In a loudspeaker, coil heats up by functioning and if the ferrofluid is kept in place by the magnetic field of the magnet fixed on the loudspeaker's horn the heat can be dissipated. Particularly high power loudspeakers are to be equipped with ferrofluid. Ferrofluid around the coil improves the quality of the speaker by damping unwanted resonances and notice.

C. Inertial and viscous damper

As magnetic fluids can used as dampers in loudspeakers. unwanted vibrations is associated to motors can be damped by ferrofluid based inertial and viscous dampers, Mainly stepper motors gives very good results with ferrofluid dampers. The ferrofluid has an unique property of keeping a magnate floating in it though the mass of the magnet is much higher than that of the ferrofluid. The magnetic field gradient pulls the magnetic fluid to the region under the immersed pole of the magnet, causing a 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. A non-magnetic body can "levitate" if there is a magnetic field gradient applied on the ferrofluid, causing a magnetic pressure gradient in the fluid [11].

A stepper motor operated at its natural frequency may have large 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[12].

D. Magnetic colloids used to dope liquid crystals

The use of magnetic colloids to dope liquid crystals was proposed by F. Brochard and P. G. de Gennes [13] in 1970. They proposed to introduce anisotropic magnetic nanoparticles ($L=d$ » 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 [14] the magnetic field necessary to orient liquid crystals. According to experimental observations with lyotropic nematic liquid crystals [15], above a minimum value of the concentration of particles, *cm*, the liquid crystalline matrix collectively follows the orientation of the magnetic particles. Rault and others [16] 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). 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 [17][18]. Since one of the basic substances of lyotropics is water, their doping with water-based ferrofluids is straightforward. Typical concentrations used in lyotropics, for many practical purposes, are c » 10^{13} *particles/cm*^{3}. At this concentration, there were observations of no significant changes in the transition temperatures, birefringence and elastic constants with respect to pure liquid crystals.

E. Doping of lyotropic liquid crystals with magnetic particles

Ferronematic and ferrocholesteric lyotropic liquid crystals were prepared for the first time by Liébert and Martinet [19] mixing a water-based ferrofluid 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 [20].

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, *Âa* 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 [21, 22].

Linear optical techniques are widely used to investigate the dynamic behavior of ferronematics as a function of time and strength of the applied magnetic field (**H**) [17].

F. Ferrofluid for targeting drug delivery to tumor cells

Ferrofluid drug targeting allows the concentration of drugs at a defined target site under the influence of a magnetic field. Site-directed drug targeting is one way of local or regional anti tumor treatment. The drug & an appropriate Ferrofluid are formulated into a pharmaceutically stable formulation which is usually injected through the artery that supplies the drug to target organ or tumor in the presence of an external magnetic field. Prolonged retentions of the ferrofluid drug carrier at the target site delay the clearance and facilitate extra vascular uptake [25-27].

G. Ferrofluid for bioseparation

Bioseparation is an important phenomenon for the success of several biological processes. Amongst the different bioseparation techniques, ferrofluid separation is the most promising. Particles that are bound to ferrofluid can be used to remove cells and molecules by applying magnetic fields and, to concentrate drugs at anatomical sites with restricted access. These possibilities form the basis for well-established biomedical applications in protein and cell separation. The isolation of various macro molecules such as enzymes, enzyme inhibitors, DNA, RNA, antibodies and antigens from different sources including nutrient media, fermentation broth, tissues extracts and body fluids, has been done by using magnetic absorbents. In case of enzyme separation, the appropriate affinity legends are immobilized on polymer coated ferrofluid carrier[25-26].

Immobilized protein A or protein G on silanized ferrofluid and fine magneto tactic bacteria can be used for isolation and purification of IgG[27_29].

H. Ferrofluid induced hyperthermia for treatment of cancer

Hyperthermia is the heat treatment of organs or tissues, such that the temperature is increased to 42–46°C and the viability of cancerous cells reduced. It is based on the fact that tumor cells are more sensitive to temperature than normal cells. In hyperthermia it is essential to establish a heat delivery system, such that the tumor cells are heated up or inactivated while the surrounding tissues (normal) are unaffected.

I. Hyperthermia

i) **Intracellular hyperthermia** Ferrofluid particles selectively heat up tissues by coupling AC magnetic field to targeted magnetic nano particles. As a result, the whole tumor can be heated up uniformly this is called intracellular hyperthermia. It has been shown that malignant cells take up nine times more ferrofluid nano particles than normal cells. Therefore the heat generated in malignant cells is more than in normal cells. Hence, the temperature rise in the region of tumor is higher than in the surrounding normal tissues. It is therefore expected that this therapy is much more effective [31].

ii) **Magnetic fluid hyperthermia (MFH)** Magnetic fluid hyperthermia is based on the fact that sub domain magnetic particles produce heat through various kinds of energy losses during application of an externa AC magnetic field[32].

iii) **Combination therapy:** There also exists the combination therapy which would induce hyperthermia treatment followed by chemotherapy or gene therapy. A combination of chemotherapy or radiation therapy with hyperthermia is found much more effective than hyperthermia itself[33-36].

J. Control of pharmacokinetic parameter and improvement of drug release:

Macromolecules such as peptides have been known to release only at a relatively low rate from a polymer controlled drug delivery system, this low rate of release can be improved by incorporating an electromagnetism triggering vibration mechanism into the polymeric delivery devices with a hemispheric design, a zero-order drug release profile is achieved[37].

K. Ferrofluid targeting of radioactivity

Ferrofluid targeting can also be used to deliver the therapeutic radioisotopes. The advantage of these method over external beam therapy is that the dose can be increased, resulting in improved tumor cell eradication, without harm to adjacent normal tissues[24].

L. Contrast agent for MRI

The most important application of ferrofluid is as contrast agent for magnetic resonance imaging in diagnosis of diseases[46]. The ferrofluid is injected as an agent and guided to reach and concentrate at particular site, to make investigation easy and informative.

M. Tissue fixation

Ferrofluid have been successfully used in gastrointestinal surgery for tissue fixation. Which form hermetic seal after surgery and possibility of the gastrointestinal tract is maintained and the patient can able to eat immediately after operation[39].

N. Retinal repair

Magnetically guided ferrofluid nanoparticles were used in retinal repair[39]. The ferrofluid nanoparticles are used to formulate the stable compositions with other drugs and injected as per the requirement. The repair is faster and smoother due to use of ferrofluid nanoparticles.

O. Defect detection

Ferrofluid have application to detect defect in ferromagnetic materials and components based on magnetic flux leakage (MFL) technique[39]. Due to defects, the magnetic flux leakage is disturbed and this can be easily detected using ferrofluids.

P. Noise reduction

Ferrofluid can be used to reduce the noise level of certain equipment such as home care kidney dialysis machines[38]. It can be achieved by reducing the vibrations, using the magnetic fluid.

Q. Energy harvesting

Ferrofluids enable an interesting opportunity to harvest vibration energy from the environment. Existing methods of harvesting low frequency (<100 Hz) vibrations require the use of solid resonant structures. With ferrofluids, energy harvester designs no longer need solid structure. Ferrofluid is placed inside a container, wrapped with a coil of wire. The ferrofluid is then externally magnetized using a permanent magnet. When external vibrations cause the ferrofluid to slosh around in the container, there is a change in magnetic flux fields with respect to the coil of wire. Through Faraday's law of electromagnetic induction, voltage is induced in the coil of wire due to change in magnetic flux[39].

R. Ferrofluid to treat ulcers and fistulas

The method comprises inserting ferrofluid into fistulous tract and attaching a permanent magnet to its outer opening. The fixed position of ferrofluid in fistulous tract carefully seals the fistula, not interfering with the healing process[39]. Thus it prevents the infection to occur, and helps speedy healing.

S. Magnetic nano particals to destroy cancer cells

Under magnetic field, multifunctional nanoparticles can reach into cancer cells, piercing their membranes. Nanoparticle core is iron oxide. The researchers have discovered that under magnetic field, the particles inside cancer cells are able to break though the membrane of cancer cells[39].

T. Fluid control in Microchanals

Fluid control, namely pumping and valving, is critical for microchip-based chemical processing. For many microchip applications, electrokinetic effects alone are sufficient to provide all necessary fluid control. Electrokinetic pumping, i.e., electroosmosis, has been very effective in microfluidics through the application of high voltage to the fluid access points and reservoirs on the chip [40–43].

The work presents a demonstration of the ability of ferrofluid plugs to function as seals, valves and pumps in standard microfabricated glass structures. To date most of our work on ferrofluidic devices has used air as the fluid in the channels. Potential microfluidic applications for a ferrofluidic pump could use the pressures generated on the chip itself to do work. Such devices could be used in gas phase micro-reactors or as pressure sources for driving liquids downstream in a microchannel network[44].

U. Electrical Transformers

Ferrofluids are able to provide 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, while also minimizing the effect of moisture on typical insulating fluids. The benefits of ferrofluid may be utilized to design smaller, more efficient new transformers, or to extend the life or loading capability of existing units. Ferrofluid for liquid-filled transformer applications.[46]

III. CONCLUSION

The ferrofluid or the magnetic fluid has very amazing properties, which other fluids do not exhibit. These properties are exploited and used in different applications in the field of Engineering, Technology and Medicine. The new applications are still emerging and there is a vast scope of new applications to be developed.

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