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Characteristics of ferro fluid

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Abstract

This paper focuses on the synthesis and characterization of ferro fluid (smart fluid). The colloidal mixtures of magnetite in carrier fluid were made by different chemical processes. The characteristics like particle size, turbidity, density, viscosity, and damping were studied. The average particle size after repeated filtering measured to 12 nm. The turbidity variation was found to be almost negligible. The damping coefficient varied from 0.2418 Ns/m to 0.8348Ns/m in the magnetic field. The effect of magnetic field on viscosity was studied on in house made viscometer and calibrated with the existing Redwood viscometer. It was possible to change the viscosity with the change in magnetic field. Such smart fluid could be used in a semi active shock absorber of a vehicle for better performance.

Keywords: Ferro fluid, viscosity, magnetic field, Smart fluid.

Introduction

Conventional vehicle suspensions achieve the road induced vibration isolation through passive means such as springs and dampers or passive shock absorbers. With the semi active suspension, the dynamic sag due to body roll in turns can be two to three times smaller. Semi active suspension system started in the early 1980's with the introduction of the first variable damping shock absorbers. These variable dampers typically changed the damping from soft to firm and *vice versa*, through a manual or slow adaptive control (Hrovat, 1997). The variation in damping characteristics of the shock absorber is done by instantly changing the viscosity of the liquid magnet, used as absorber oil, by changing the magnetic field which should be sensitive to road disturbances. Ferro fluid is very much suitable for such applications.

Ferro fluids (compound of Latin ferrum, meaning iron, and fluid) are colloidal suspensions of fine (~ 0.05-15 nm) dispersions of magnetically soft, multi domain nano particles, such as Fe_3O_4, coated with surfactants in a carrier liquid. When there is no magnet nearby, the magnetite particles in ferro fluid act like normal metal particles in suspension. But in the presence of a magnet, the particles are temporarily magnetized. Ferro fluids respond to an external magnetic field. This enables the fluid's location to be controlled through the application of a magnetic field. The particles are so small in ferro fluids that they will not settle over time, but remain in place as long as a magnetic field is present. Treatment of particles with surfactants prevents them from clumping up, causing the material to remain stable and act predictably. They form structures within the fluid, causing the ferro fluid to act more like a solid. When the magnetic field is removed, the particles are demagnetized and ferro fluid acts like a liquid again. The apparent viscosity of these fluids can be changed significantly within milliseconds by the application of an external magnetic field.

Much research has been centered on ferro fluids that contain small particles of magnetite, Fe_3O_4. Magnetite can be produced by mixing Fe (II) and Fe (III) salts together in a basic solution. The particles must remain small and separated from one another in order to remain suspended in the liquid medium. Magnetic and van der Waals interactions must be overcome to prevent the particles from agglomerating into larger particles. Thermal motion of magnetite particles that are smaller than ~100 angstroms in size is sufficient to prevent agglomeration due to magnetic interactions. Surfactants prevent the nanoparticles from approaching one another too closely. Ferrofluid is a unique material that acts like a magnetic solid and like a liquid. Each tiny particle is thoroughly coated with a surfactant to inhibit clumping. Large ferromagnetic particles can be ripped out of the homogeneous colloidal mixture, forming a separate clump of magnetic dust when exposed to strong magnetic fields. The magnetic attraction of nanoparticles is weak enough that the surfactant's van der Waals repulsion is sufficient to prevent magnetic clumping or agglomeration. Ferrofluids usually do not retain magnetization in the absence of an externally applied field and thus are often classified as "superparamagnets" rather than ferromagnets. The viscosity of the fluid, the tiny size of the particles, and the particles' constant motion keep the solids from settling out.

Characteristics of ferrofluid and it's applications have been studied by several researchers. An analytical approach based on the coulombian model of a magnet is used as a general method for studying the mechanical properties of a ferrofluid seal. The fundamental Maxwell's equations define the concept of magnetic energy of the ferrofluid seal by using only the three dimensional equations of the magnetic field created by ring permanent magnets radially magnetized (Ravaud & Lemarquand, 2009). A deformable mirror is made of a magnetic liquid

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whose surface is actuated by a triangular array of small current carrying coils and the mirror can correct a 11 µm low order aberrated wave front to a residual RMS wave front error 0.05 µm. Recent developments show that these deformable mirrors can reach a frequency response of several hundred hertz (Brousseau, 2008). Extensive research work has been done on the fluid dynamics in the presence of magnetic field for magnetorheological fluids and ferro fluids using the finite element simulation (Tomasz Strek, 2005). It is possible to use magnetic fluid to measure volume of non-magnetic body of random shape. Technique is based on the detection of change in the inductance of the coil with ferro fluid as core when body is immersed. Inductance is related to the volume of the body (Upadhyay Shail, 2006). The motion and shape of a ferro fluid droplet placed in a non-magnetic viscous fluid and driven by a magnetic field are modeled numerically. The governing equations are the Maxwell equations, momentum equation and incompressibility (Afkhami *et al.,* 2008). The drops of a ferro fluid floating in a non-magnetic liquid of the same density and spun by a rotating magnetic field are investigated experimentally and theoretically. The rotational motion of the drop is most easily studied experimentally for the non-axis symmetric shape. This effect may contribute to the difference in the experimental and theoretical results for the rotation frequency of the elongated drop (Lebedev *et al.,* 2003). The equilibrium magnetization of concentrated ferro fluids described by a system of polydisperse dipolar hard spheres is calculated as a function of the internal magnetic field using the Born-Mayer or cluster expansion technique (Huke & Lu¨cke, 2003). The characterization has been much useful for applications of ferro fluid.

Preparation of ferro fluid

There are several methods of synthesis of magnetite nano particles. After some initial trials, ferrofluid is prepared using two methods: The first method uses flammable substances and generates heat and toxic fumes. The ingredients are: ammonia - Oleic acid, ferric chloride ($Fecl_3$), steel wool, distilled water, kerosene, heater, filter paper. Synthesis Procedure is: reduce $FeCl_3$ to $FeCl_2$, react in 2:1 ratio of $FeCl_3$: $FeCl_2$ in ammonia. The Fe_3O_4will fall out of the solution. Heat the magnetite solution to just below boiling and stir in 5 ml oleic acid. Add kerosene as a carrier fluid. Discard water. The second method is to get iron oxide particles of mostly nano spheres, the chemicals used are: Sodiumhydroxide (NaOH), Ironchloride ($FeCl_3$), Sodium hexametaphosphate (NaH_2PO_4), Double distilled water. Synthesis procedure is: Prepare 0.5 M NaOH solution in distilled water, Add 0.01 M solution of Fe $(NO_3)_3$, Stir till pH becomes 10.7, Wash the precipitate with distilled water several times till pH becomes ~8.7, Add 1 M HCl, Stir, Add 0.1 M solution of NaH_2PO_4, Stir, Add water and heat the solution to ~100 deg. Celcius, Wash and dry the precipitate in air at 100 deg. Celcius. Fe_2O_3 particles are obtained. Photographs (Photograph 1) of the ferrofluid prepared by any one of these methods reveal the effect of a magnet. The ferrofluid liquid turns into a paste like material in presence of a magnet.

Measurements and experiments

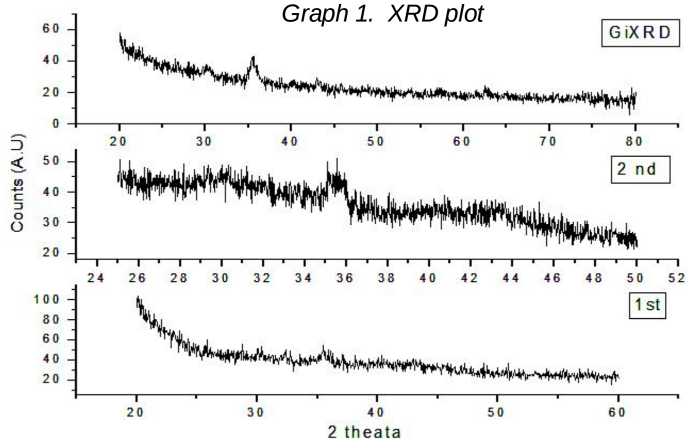
All the materials-may be metals, semiconductors or insulators-have size dependent physical-chemical properties below a certain critical size. However, for most of the materials this critical size is below ~100 nm. At such a small size even the shape of the material and interactions between nano materials decide the properties of the material. This opens up a huge possibility of tailor-making the materials, which have different properties just due to their size, shape and/or assembly. Measurements on single nano particles, rods, tubes etc. would inherently be difficult, though not impossible. However measurements on nano crystalline solids, thin films etc. are possible using some conventional methods.

Results of X - ray diffraction (XRD)

The nano particles are separated out from the liquids as a precipitate by using a centrifuge approximately at 2000 to 3000 rpm. Precipitate is washed with solvent,

Photograph 1. Ferro fluid with and without magnet.

Graph 1. XRD plot



ethanol, to remove unreacted chemicals or by products. Precipitates are then dried to get sample in the form o powder. The filtered particles from the ferro fluid prepared chemically, are taken to XRD machine -Brukar D8 discover. As per the Graph 1 obtained from XRD, the diffraction peaks in nano crystalline particles are broadened compared to polycrystalline solid. The broadening is caused by the nano particle size. For extremely small particle size <2 nm, the broadening of diffraction peaks becomes very large. The average particle size is 12 nm.

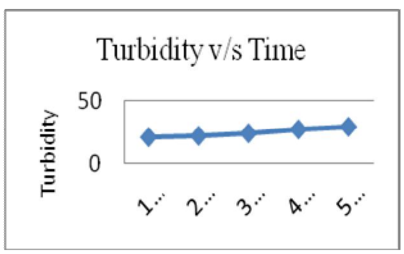
Results from scanning electron microscope (SEM)

In SEM the electron beam can be focused to a very small spot size using electrostatic lenses. The fine beam is scanned on the sample surface using a scan generator and back scattered electrons are collected by an appropriate detector. The SEM result of fine filtered particles shows the maximum particle size to be 32 nm.

Turbidity measurement

The experimental set up for turbidity measurement is focused on first putting the prepared ferro fluid in the centrifuge at 2000 rpm and rotating for different periods to maximum value of five minutes. Assuming that the field conditions will not be worst than this for simple applications like in a shock absorber. The liquid is taken out from centrifuge and the turbidity is measured in the EI digital turbidity meter. The colloidal suspension of the differential heavier particles of magnetite, Fe_3O_4 in the carrier fluid result into momentary separation for few seconds after 2000 rpm.

Graph 2. Turbidity v/s time



The Graph 1 shows the variations in turbidity with time at 2000 rpm. For different rpm values the results are not repetitive. After some time, slowly the turbidity returns to its initial value and the effect of rpm vanishes. The particles do not settle at the bottom and the liquid remains in the colloidal form in general. The initial filtered particles were repeatedly filtered to finally arrive at the turbidity meter value wherein the separation of the fine particles does not occur.

Measurement of density

There is a variation in the density for different quantities of ferro fluid due to the reason that the samples are taken from different lot of preparations and the variation in the particle sizes. For the same lot and with different sample sizes the variation is not considerable. To get the consistency in the results the ferro particles were filtered repeatedly and added with the carrier fluid till the repeat results were obtained. The density of ferrofluid= 1.1423 gms/ml.

Damping coefficient of ferro fluid compared with other standard fluid

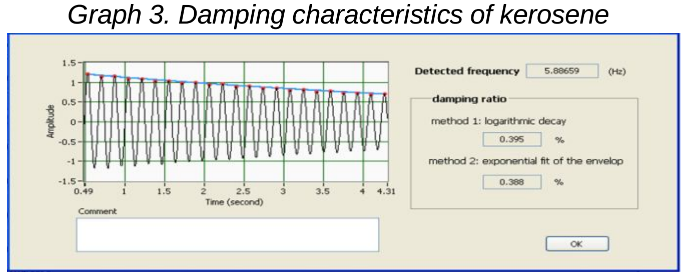
Photograph 2. Vibration Fundamental Training System (VFT)

The damping behavior of ferro fluid is observed on Vibration Fundamental Training System (VFT). A container is filled with the ferro fluid and a flat disc floats on the fluid. The disc from the upper side is attached to a spring and together the system constitutes a spring and a dash pot system. The system is made to vibrate as per the input data (Photograph 2).

The in house prepared ferro fluid has kerosene as the carrier fluid, and therefore the kerosene is taken as the reference fluid for comparison with the ferro fluid. Shock absorber suspension oil is taken as other fluid for comparison with the ferro fluid.

[5.a] Kerosene as a damping fluid
(Graph no.3)

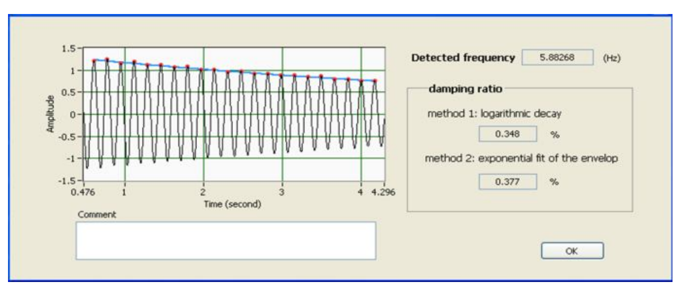
Graph 3. Damping characteristics of kerosene



The natural frequency of the system with kerosene is detected as, f = 5.88659 Hz, The circular frequency , ω_n = 36.9865 rad/s ,The logarithmic decrement ,δ = 0.395,The damping ratio ,ζ = 0.0627, The damping frequency , ω_d = 36.8391 rad/s, c_c = 3.69865,The damping coefficient, $c = \zeta\, c_c = 0.23190$ Ns/m

[5.b] Front shock absorber oil as a damping fluid
(Graph no.4)

Graph. 4. Damping characteristics of shock absorber oil



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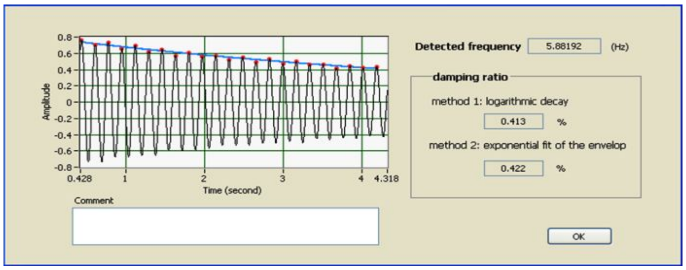
The natural frequency of the system with Shock absorber oil is detected as, f = 5.88268 Hz, The circular frequency , ω_n = 36.9608 rad/s, The logarithmic decrement ,δ = 0.348, The damping ratio ,ζ = 0.0553, The damping frequency , ω_d = 36.8462rad /s, c_c = 3.6846 Ns/m. The damping coefficient, c = 0.2037 Ns/m.

[5.c] 'In house made Ferro fluid' as a damping fluid (Graph no.5)

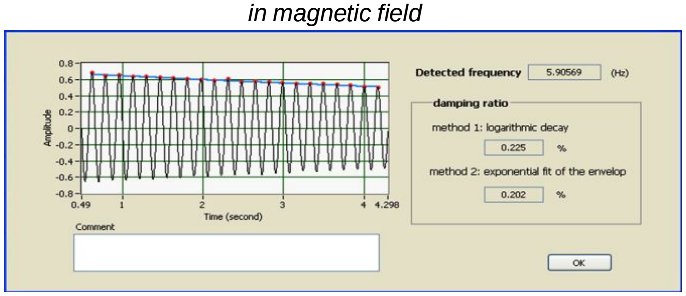
Graph 5. Damping characteristics of ferro fluid



The natural frequency of the system with Ferro fluid is detected as, f = 5.88192 Hz, The circular frequency , ω_n = 36.9571rad/s, The logarithmic decrement ,δ = 0.413,The damping ratio ,ζ = 0.06559, The damping frequency , ω_d = 36.877 rad/s, c_c = 3.6957 Ns/m, The damping coefficient, c = 0.2418 Ns/m

[5.d] 'Ferro fluid in magnetic field 'as a damping fluid (Graph no.6)

Graph 6. Damping characteristics of ferro fluid in magnetic field



The natural frequency of the system with ferro fluid in magnetic fieldis detected as, f = 5.90569 Hz, The circular frequency , ω_n = 37.1065 rad/s, The logarithmic decrement ,δ = 0.225, The damping ratio ,ζ = 0.03578,The damping frequency , ω_d = 37.0827 rad /s, c_c = 3.7106,The damping coefficient, c = 0. 8348 Ns/m.

The damping coefficient of ferro fluid is compared to the standards selected. As the ferrofluid is subjected to the magnetic field, the damping coefficient value changes considerably.

Viscosity measurement

Fluid viscosities can be measured in several ways with different viscometers. Liquid viscosities are sometimes determined by measuring the time required for a given quantity of liquid to flow by gravity through a precision opening. A liquid of high mass density flows through the viscometer more quickly than does a less dense liquid of same absolute viscosity. In the magnetic field ferrofluid changes its viscosity and therefore it's apparent viscosity is difficult to measure in magnetic field. Modification is done on a redwood viscometer and setting is done comparing with the earlier readings taken on conventional redwood viscometer (Photograph 3);

Photograph 3. A conventional redwood viscometer

Viscosity of Shock absorber oil (a standard for comparison) using conventional redwood viscometer presented in Table 1. Viscosity measurement on magnetised redwood viscometer presented in Table 2. Photographs of the components taken of the modified viscometer prepared in house (Photograph.4; Graph 7; Fig.1).

Table 1. Redwood viscometer

Water T (^{O}C)	Oil T (^{O}C)	Time in sec. for flow of 50ml of oil
20	20	94
29	29	65
47	47	45

Table 2. Modified viscometer

Name of fluid/ position of tip	Time to flow 50 ml fluid (in sec)		
	X=8 mm	X=10 mm	X=12 mm
Ferrow fluid (with magnet)	43.32	46.49	1045.07
Ferrow fluid (without magnet)	42.47	43.57	63.83
Kerosene	39	41.09	54.66
Shock up oil	176.87	174.09	175.88
Water	39.73	39.51	47.66

Photograph 4.Various modified components

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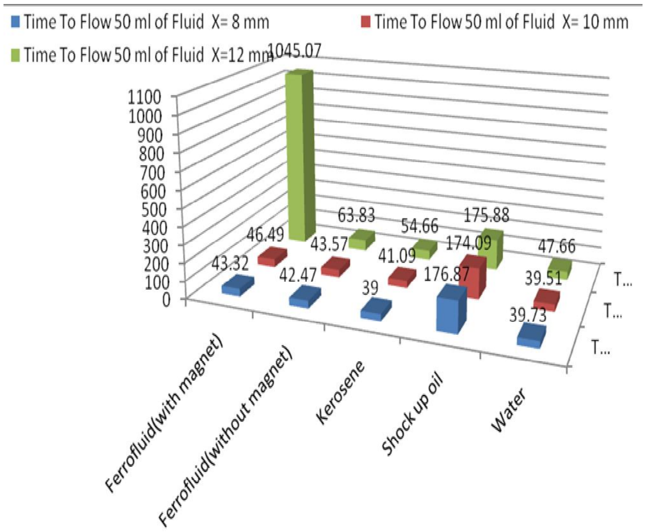
Graph 7. Viscosity measurements for different settings of viscometer.



Conclusion

Some of the mechanical properties have been observed using different experimental techniques which will enable further use of the ferro fluid to various applications. With the method of preparation of ferro fluid, the mechanical properties like: density, particle size, turbidity, viscosity with and without magnetic field are measured. The ferro fluid prepared in house contains nano particles. The nano particles range up to 32 nm. The average particle size is 12 nm. At this value the density variation and the turbidity settlement stabilizes. From SEM photograph it appears that the nm particles are mostly spheres. The effect of external magnetic field on the property of ferro fluid, like viscosity cannot be measured by the conventional method and therefore modification is done on the conventional redwood viscometer. The modified viscometer is calibrated with conventional viscometer with standard fluid and then the viscosity is compared for the ferro fluid. One can get the desired viscosity of the ferro fluid after the setting the magnetic field. When the ferrofluid is subjected to the magnetic field then the damping coefficient value changes considerably. For a shock absorber where semi active suspension is desirable, there the use of the ferro fluid with coupling (c = 0.8348 N -sec/m) and decoupling(c = 0. 2418 N -sec/m) with the magnetic field for the instant change in damping coefficient is recommended. It is thus possible to get the instant change in the viscosity and therefore the instant change in the damping characteristics of the viscous fluid.

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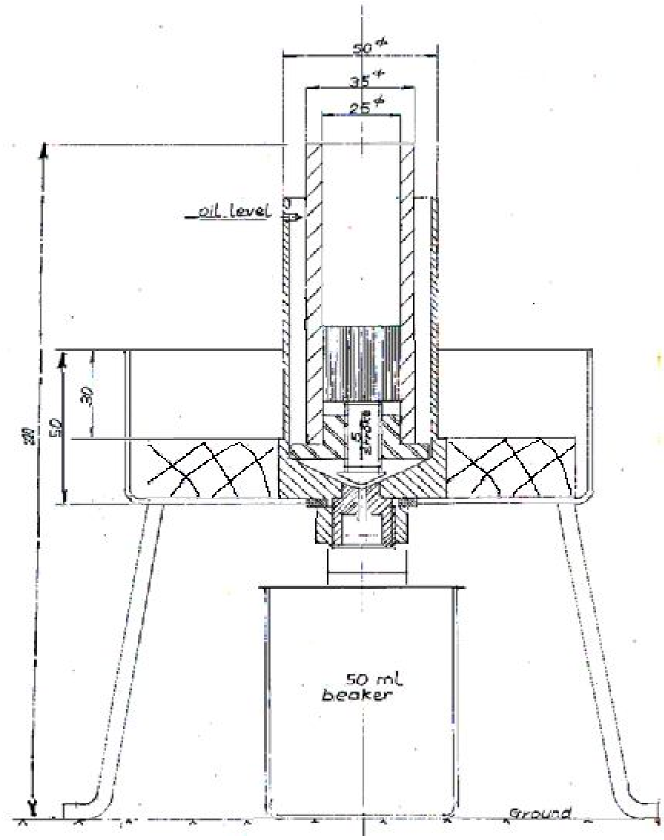
Fig.1. Modified Redwood viscometer



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