Synthesis of Magnetorheological Fluid using Electrolytic Carbonyl Iron Powder for Enhanced Stability

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Abstract. Magnetorheological (MR) fluids is synthesized using micron-sized electrolytic carbonyl iron (CI) particles and vacuum grease as additive and their rheological behaviours were investigated in terms of particle alignment by controlling magnetic field, also the effect of surfactant Triton X100 was investigated. The overall rheological characteristics and sedimentation characteristics of the synthesised samples of MR fluids were compared with Lord 132DR MR fluid using rotational Rheometer which has magnetic cell. It was establish that combination of electrolytic CI powder with vacuum grease and Triton X-100 improves the stability of the fluid by reducing sedimentation

1 Introduction
Magnetorheological fluids are smart materials which changes its properties under the effect of magnetic field. When they change their states from liquid to solid state, their viscosity, load carrying capacity also changes. The three components in MR fluids are carrier fluid, magnetic particles and additives.

The magnetic particle are dispersed in carrier fluid, should be magnetically active in presence of externally applied magnetic field. The dispersed phase can be paramagnetic, ferromagnetic and ferromagnetic materials [1]. The commonly choose volume fractions for MR fluid to maintain decent yield stress in the magnetic particles is about 0.3-0.5. MR fluids "off-state" viscosity rises, significantly and undesirably with higher volume fractions of the particles, also leading to higher strength of MR fluids. [3], also yield stress within a moderate magnetic field strength (0.1-1 T) can range between 10–100 kPa [4]

There are also some significant problems associated with conventional MR fluids. One of the disadvantages is settling down of dispersed particles in MR fluids because of centrifugal or gravitational sedimentation. Also, the settled magnetic particles forms tightly knit Sediment or a “lump” which, once formed, makes it extremely difficult to redisperse the MR fluid. These problems arise since the iron particles have density approximately 7.8g/cm³ whereas the carrier fluid has density in range of 0.8 to 1.0g/cm³ [6]. Various methods have been tested to improve stabilization such as adding nanoparticles, coating magnetizable particle with polymers and using non magnetizable particles or adding surfactants [4]. The advantages of silicone oil such as good heat transfer characteristics, oxidation resistance, good temperature stability, high flash points and low vapour pressure are considered for selecting silicon oil as the carrier fluid. Also, among all available magnetic

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particles, extensively CI are chosen as dispersed phase for MR fluids, since they show superior magnetic permeability, common availability and soft magnetic property. Still, its abrasion with equipment and sedimentation drawback because of its high density. In the industrial application of MR fluid fluids based on CI have a great disadvantage of sedimentation because of density difference of suspended particles.

During investigation, CI powder – Electrolytic, size in micron were used as suspended particles in the mixture of Vacuum Grease and silicon oil as the carrier fluid to prepare MR fluid. Yield stress and fluid-stability is improved by adding Vacuum Grease and Triton X-100 as additive and surfactant respectively. Under variable composition sedimentation ratio of the MR fluids were studied, also the yield properties and flow behaviour were measured by Rheometer, exhibiting effect of electrolytic magnetic CI particles in silicon oil as improved yield stress and stability.

2 Experimental Details

Experimental details are discussed in this section.

2.1 Materials

Silicone oil (Chemind Chemicals, Calicut, India) is used as the carrier fluid and electrolytic carbonyl Iron Powder (EC10TR, Electrolytic reduced powder, Industrial Metal Powders, Pune, India) as the suspended particle in the system. The normal particle size distribution and apparent density of synthesized MR fluid are 14.47 μm and 1.1 g/cm³, respectively. The iron content of the powder is 99.56% whereas hydrogen losses are 0.49 %. In order to enhance polarization of particles and stability when subjected to external induced magnetic field surfactant and additives are used. They get readily absorbed on the magnetic particles. Vacuum grease is used as an additive whereas Triton X 100 as the surfactant to disperse particles throughout the fluid.

2.2 Method of synthesis

Silicone oil and grease were primarily mixed using the stirrer for 2 hours to attain homogeneous mixture. To the prepared mixture carbonyl iron powder and Triton X was added part by part in 10 steps and then stirred for another 9 hours to obtain the Silicon oil and CI suspension. Various samples of MR fluid were synthesized with different composition of silicon oil, CI powder, Grease and Triton X100. MR fluid with various volume fractions of magnetic CI powder is prepared. The percentage of vacuum grease in all the samples is 10 % volume fraction and Triton X-100 of 2 % volume fraction is added. The synthesised MR fluid composition and its abbreviation symbols are listed in Table 1.

| Composition of sample                                      | Symbol       |
|----------------------------------------------------------|--------------|
| Lord 132 DG MR fluid                                     | MRF          |
| 30 % CI power +10% vacuum grease+ Silicone oil            | MRF30        |
| 35 % CI power +10% vacuum grease+ Silicone oil            | MRF35        |
| 40 % CI power +10% vacuum grease+ Silicone oil            | MRF40        |
| 30 % CI power +10% vacuum grease+ 2% Triton X+ Silicone oil | MRF30TX2     |
| 35 % CI power +10% vacuum grease+ 2% Triton X+ Silicone oil | MRF35TX2     |
| 40 % CI power +10% vacuum grease+ 2% Triton X+ Silicone oil | MRF40TX2     |

2.3 Rheological and sedimentation tests

The Sedimentation rate was measured by pouring MR fluid into a 50ml graduated cylinder up to 10 cm. The cylinder is plugged to dodge any influence of the atmosphere. Sedimentation of particles results in the development of two layers, namely upper layer as L₁ and a lower layer as L₂ respectively measured from the bottom. MR fluid sedimentation ratio can be described as a ratio of the height of the upper layer (L₂) to the total height of the MR fluid (L₁). The samples are kept for 7 days and
values are recorded, the graph for sedimentation ratio against time is plotted. Faster is the decrease in value of sedimentation ratio lower is the sedimentation stability, and smaller is the final value of sedimentation ratio.

MR characteristics were studied in both on and off state of magnetic field using a rotational Rheometer (MCR 102, Anton Paar, Delhi, India) with a magnetorheological equipment (MRD 170, Anton Paar, Delhi, India) uniform magnetic field are generated. Measuring system was made of parallel-plate, non-magnetic metal whose diameter was 20 mm and a gap of 1 mm was maintained to reduce the radial magnetic forces effect on measuring systems shaft

3 Results and discussion
The morphology study of the electrolytic CI powder with the suspended particles in the MR fluids was carried under scanning electron microscopy (SEM) as shown in Figure 1 shows the characteristic morphology of CI particles by SEM. The CI particles in general have a spherical-shape and show particle size distribution. The particles are align to form chain-like structure as result of the magnetic field can be transformed into an accumulated structure, magnetic particle provides surface and contact area for the surfactant and stabilizer to adsorbed on the surface resulting in lower sedimentation rate, also the particles suspended in fluid exhibit surface interaction with the fluid.

Figure 1  SEM image of Electrolytic CI powder particles and particle suspended in MR fluid.

The shear rate increases with shear stress. The fluid offers more resistance to the increased shear rate. Figure 2 represents the variation of shear stresses with respect to shear rate of micron-sized CI MR fluids, with variable volume fraction also the effect of surfactant Triton X 100 on shear rate. The values of synthesized fluid are compared with Lord 132 DG MR fluid and it can be noted that the highest value is represented by MRF30 (115.02 Pa), whereas MRD40TX2 reads the lowest value, implying that increase in volume fraction of CI particles decreases shear rate also presence of surfactant has an insignificant effect.

The off-state viscosity of synthesized MR fluid decreases with the increase of shear rate value. Figure 3 represents the change of Shear viscosity for CI in silicon oil as a function of shear rate. The off-state viscosity is linear to the shear rate of MR fluid. As in case of Lord 132DG (MRF) the change is minimum which is desired, but all the samples prepared shows higher variation value as compared to MRF. The fluid exhibiting lowest change of the value is MRD40TX2 (0.109), the presence of surfactant in the fluid enhances the ability to resist change in viscosity with gaining shear rate.
Figure 2 Shear stress and shear rate curve for micron-sized CI based MR fluid

Figure 3 Shear viscosities for CI in silicon oil as a function of shear rate.

The plot of sedimentation ratio against time is plotted for a duration of 7 days in hours. Figure 4. shows the variation in sedimentation ratio as a function of time for the synthesized MR fluid samples. Influence of additive and stabilizer with the variable volume fraction of particles in the carrier fluid is analysed and it is observed that Lord 132DG performs best with least sedimentation test. Out of synthesized MR fluids, MRF35TX2 shows the least sedimentation, deducing that effect of surfactant is negligible as compared to the volume fraction of the magnetic particle.

The yield stress values of standard Lord 132DR is compared with synthesized MR fluid with variable magnetic strength. Figure 5 shows influence of magnetic field strength on yield stress of synthesized MR Fluid. MRF35 sample reads the maximum value of 90.13 kPa whereas samples of MRF45TX2 reads minimum value i.e. 41 kPa. This show effect of surfactant on yield stress is negligible whereas the effect of volume fraction has the significant effect.
4 Conclusions
MR fluids with different composition of electrolytic micron-sized particle discretized in the colloidal combination of grease and silicon oil with surfactant Triton X100 were prepared. Effect of adding CI particles and surfactant on shear stress, off state viscosity with shear rate, the variation in yield stress with respect to magnetic field strengths were investigated. Sedimentation tests were also carried out over a period of seven days.

Sample with 30% CI, 10% vacuum grease gives the highest shear stress value of 119 Pa, while the value of Lord MR Fluid is 105 Pa. Sample with 40% CI, 10% vacuum grease and 2% Triton gives the least change in off state viscosity with shear rates extending from 0 to 1100 per second. Lord MR fluid shows the comparatively higher change in off state viscosity for the same shear rate ranges. Sample with 30% CI, 10% vacuum grease gives yield stress of 90.13 kPa under the magnetic field strength of 0.7 Tesla, while lord MR fluid gives 80 kPa for the same field. Sample with 35% CI, 10% vacuum grease and 2% Triton gives lowest sedimentation ratio of 0.9, while lord MR gives sedimentation ratio of 0.98 when measured after 7 days.
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