A Review on Sedimentation of Magnetorheological (MR) fluid

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Abstract

Magnetorheological (MR) fluid is a smart material used for vibration control where the behavior of fluid can be changed from Newtonian fluid to a semi-solid material (Bingham fluids) by changing the magnetic field. Rheological characteristics of MR fluid change rapidly and be controlled effectively in presence of an applied magnetic field. The Synthesis of MR fluid involves many challenges like magnetic effect of coil, sedimentation and agglomeration of particles. In this paper, properties of magnetorheological fluids, sedimentation and agglomeration of particles have been discussed. The review covers addition of green additives like guar gum and xanthan gum, challenges in the preparation and use of magnetorheological fluids that include stability, sedimentation, agglomeration, and also oxidation of the particles. The methodology to prepare the fluid along with the process for adding selected additives was reviewed. The results showed an improvement in the reduction of sedimentation and other problems.

Keywords – *Magnetorheological (MR) fluid; Carrier liquid; Guar gum; Rheological property; Sedimentation stability*

I. INTRODUCTION

Materials whose properties can be changed correspondingly in the presence of an external energy are known as smart materials. Magnetorheological fluids are rheological materials that change their properties as a function of magnetic field and are classified as smart materials. Magnetorheological fluids were discovered by Rabinow in1948 and inspired the authors to apply the knowledge in various applications (Rabinow, 1948). The rheology of MR fluids instantaneously changes from a free-flowing liquid to a semi-solid when subjected to magnetic field. Fluid responds to current and magnetic field with in seconds. With the application of magnetic field, the magnetic particles align themselves in a chain form in the on state and again regain original form in off state. The control of the physical change of the fluid from liquid to semi-solid by the magnetic field uses it in applications such as suspension systems, brakes and valves. However, it is observed that magneto-rheological fluid have some limitations that reduce its ability to extend the application. As magnetic particles have more density than the carrier fluid of MR fluid, solid particles tend to sediment and obtain a 'cake' form under a magnetic field or static state, which is the main reason of instability of the MR fluid (Wei Ping Wu, 2006**)**. Usually general type of fluid developed by researchers using iron particles from 30% to 35% volume produces a yield shear stress of about 25– 35 kPa under a magnetic field of 0.4 T (Bica I 2004). Due to failures and defects such as hard cake formation, gravitational sedimentation and agglomeration of particles, its use is limited to only high cost applications. Stability of the fluid mainly depends on settling and sedimentation of the particles at the bottom of carrier fluid. Researchers are exploring new ways to reduce the sedimentation, hard cake formation and agglomeration of particles. Researchers are solving the sedimentation problem by adding

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surfactants or using nano iron particles .But the nano particles reduce the magnetic strength of the fluid. Authors are also coating the iron particles with polymers or natural gum powders to increase the stability of the fluid.

II. CONSTITUENTS OF MAGNETORHEOLOGICAL FLUIDS

Magnetic particles, carrier fluid, and additives or surfactants are the main elements of Magnetorheological fluids. Iron particles in microns or carbonyl iron or nano particles are used as magnetic particles. Carbonyl iron of 99% purity is mainly used because carbonyl iron particles have a high magnetic permeability and high saturation magnetization (Ashtiani et al., 2015a). Spherical shaped carbonyl iron particles are usually used as it reduces effects of wear on the walls of the container or equipment inside which the magnetorheological fluids operate. However, fiber shaped particles have shown better yield stress and low off state viscosity as compared to spherical particles (Vicente et al., 2011); Chen et al. (Jiang et al., 2011)). The concentration of carbonyl iron particles ranges from 30 to 40% by volume, and the size is normally maintained between 3 and 5 microns. Very low size may not enable the magnetorheological fluids to develop high yield stress while very large size of the iron particles could lead to erosion and heating of equipment.

The carrier fluid used is paraffin oil, silicone oil, or any other synthetic oil which has low viscosity (Jiang et al., 2011). The carrier fluid should also not chemically react with iron particles. A proper magnetorheological fluid should contain a carrier fluid with low viscosity. Also it should have inbuilt characteristics for operational temperatures and redistribution of the particles. Selection of carrier fluid depends on end application of the magnetorheological fluid. For Brake application, grease is a suitable carrier fluid, while for vibration control, silicone oil is the preferred choice owing to its properties like low viscosity, low friction characteristics, high shear strength, and high flash point (Ashtiani et al., 2015).
Additives added are usually surfactants either to prevent agglomeration of the magnetic particles or to inhibit the rate of settling of magnetic particles (Bombard et al., 2009). The use of additives is an important criteria as the particles owing to their high density have a tendency of sedimentation or settling down which if not resolved could render the device ineffective. High viscosity materials such as grease or are added to improve stability of particles against sedimentation in magnetorheological fluids. Iron naphthanate or Iron oleate are added to fluid as surfactants, while metallic soaps like lithium stearate or sodium stearate are added as thixotropic additives. Additives are necessary to control viscosity of the fluid, sedimentation of particles and inter particle friction ,in addition to prevent thickening of the fluid after several cycles of use (A.G. Olabi,2007).Some authors have tried for additives like guar gum powder and xanthan gum for reducing the sedimentation of fluid.

III. PARTICLE SIZE ANALYSIS

Sedimentation stability, yield stress and magnetic properties are influenced by the particle size distribution of magnetic particles. Analysis of particle size distribution is very important for synthesis of MR fluid (Sukhwani et al., 2007). Lemaire et al., reported the influence of particle size on MR effect and concluded that mono disperse sample is better to optimize the MR effect. This indicates that narrow size distribution leads to more MR effect. But Wereley et al. in their study concluded that use of bi disperse particles in MR fluid increases their sedimentation stability. Authors have used particle size from 0.1 micron to 10 microns with different combinations of the fluid. But the particle lesser than 0.1 micron will be subjected to random Brownian forces which destroy the chain like structure leading to decrease in the yield stress. On the other hand particles larger than 10 microns create the sedimentation problem. Sukhwani et al. has analyzed Magnetic particles using a particle size analyzer (GALAI computerized inspection system CIS-1, Particle size analyzer, Israel). Particles were dispersed in de ionized water with few drops of polyelectrolyte stabilizer to prevent the agglomeration of particles. Sodium Hexa Meta Phosphate was used as a medium to disperse the particles in this case. Figure 1 and 2 shows the particle size distribution of magnetic Electrolytic Iron (EI) particles before and after milling.

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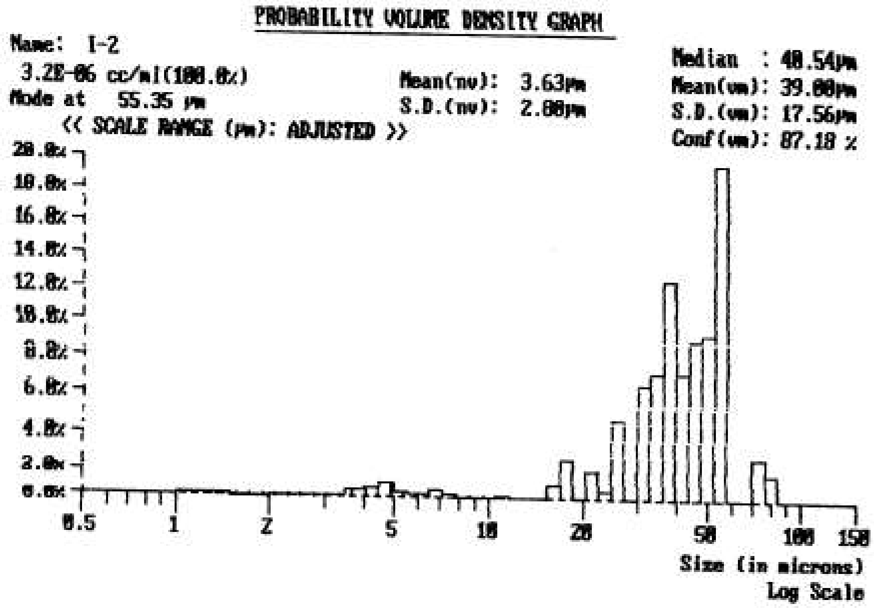

Figure 1. Graph of Volume density for Electrolytic Iron powder before milling (VK Sukhwani et al., 2007)

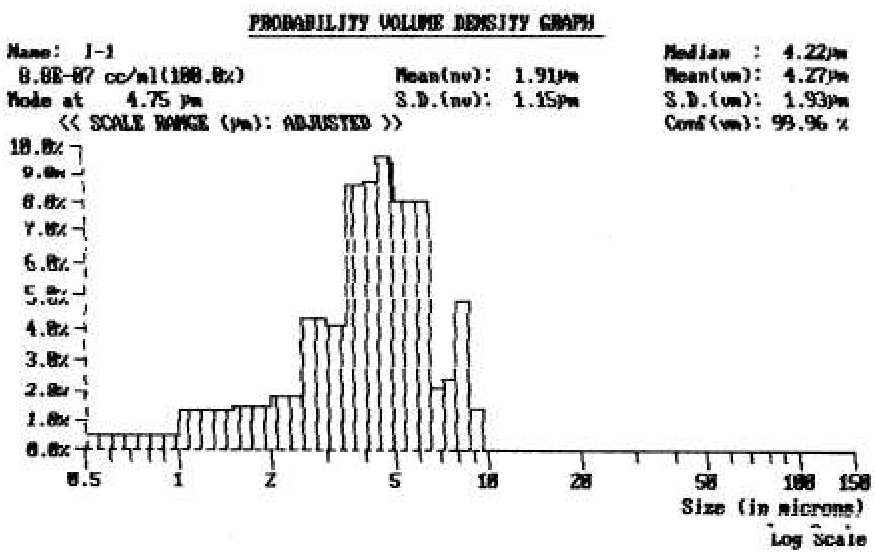

Figure 2. Graph of Volume density for Electrolytic Iron powder for Electrolytic Iron powder after milling (VK Sukhwani et al., 2007)

From figure 1 And figure 2 it is observed that before ball milling size of particle in electrolytic Iron powder is ranging from 20 to 100 microns, which will cause sedimentation of the fluid. While after ball milling volume density ranges from 1 to 15 microns. With the use of very fine powder yield stress of fluid and sedimentation ratio improves

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IV. MORPHOLOGY OF PARTICLES AND ADDITIVES

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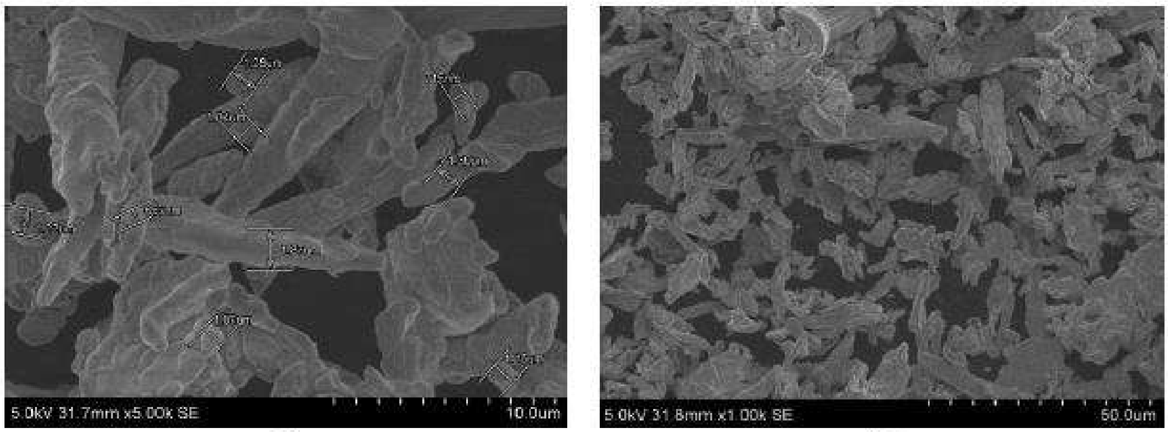
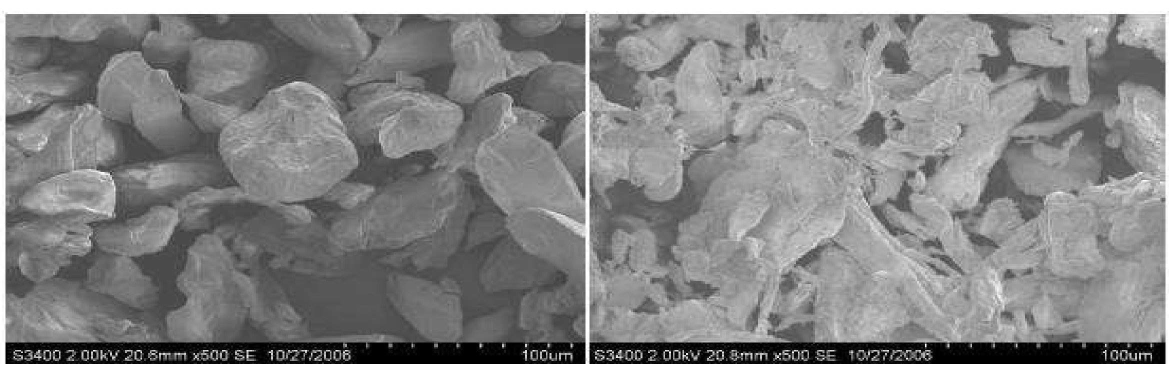
The morphological characteristics of the sample are tested with the scanning electron microscopy to find the quality of particles. Rakesh Jinaga et al. conducted the scanning electron microscopy (SEM) test and obtained that The structure of the particles is rod-like, 1–2 _m in diameter, and has an average size ranging from 1 to 10 _m. The irregular shape and size of the particles helps in superficial interactions with guar gum and makes it a better dispersant. Figure 3 explains that particles coated with guar gum will help in forming a good chain like structure and hence reduce the sedimentation.



(a) (b)

Figure 3. SEM images of electrolytic iron powder; (**a**) electrolytic iron (EI) particles shape and size, (**b**) particles coated with guar gum.(Rakesh Jinaga et al., 2019)

The morphology of the particles was studied by VK Sukhwani et al. by scanning electron microscopy (SEM facility S-3400 N, Hitachi Science Systems Japan). Very small amount of powder was placed on double sided carbon tape to prepare the sample. High vacuum was used and SEM was operated at 6-10 KV.



(a) Guar gum (b) Xanthan gum

Figure 4. SEM Images for Guar gum and Xanthan gum powder (VK Sukhwani et al., 2007)

From figure 4 it is observed that guar gum forms a granular structure while Xantahn gum obtains a fiber like structure. After formation of complete solution, the Xanthan gum additive shows good results of homogeneous mixture and reduction of sedimentation. Wei Ping Wu et al. coated the particles with guar gum for reducing the sedimentation. Guar gum is a rigid, non-ionic, polydisperse rod-shaped neutral carbohydrate polymer. Figure 5 shows the morphology of carbonyl iron powders coated with different

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contents of guar gum. Obviously, with the increase of the content of guar gum, the coating was formed gradually and finally became smooth membrane-like coating surfaces. The transmission electron microscope (TEM) images show that these particles have a shell–core composite structure. The surface of the composite particles is completely covered by guar gum layers. The thickness of the coating layer is tens of nanometers, much thinner than the radius of the particles.

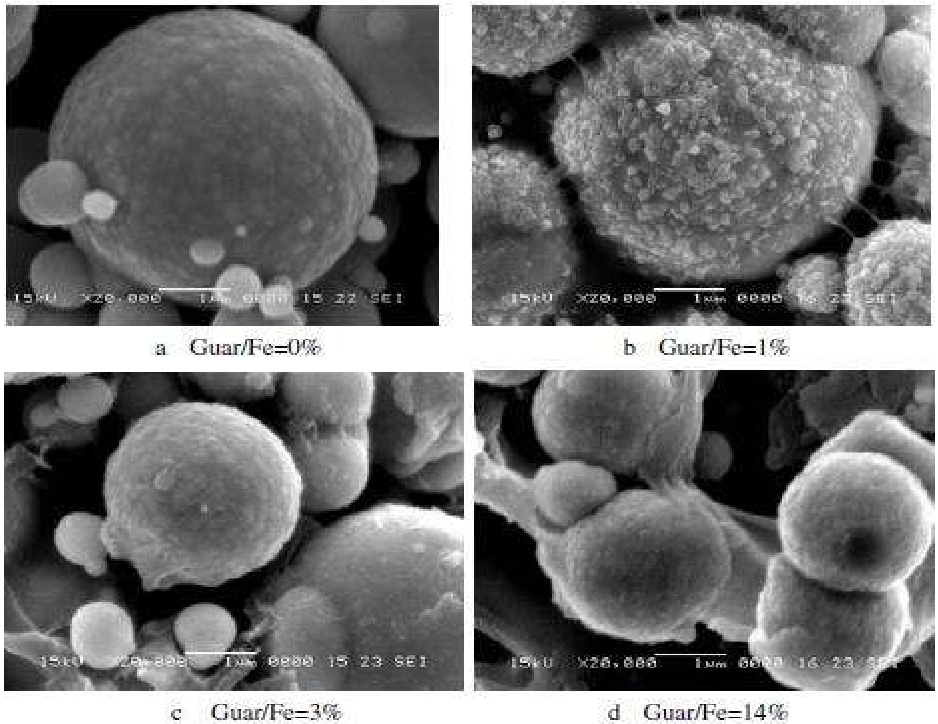

Figure 5. Morphology evolutions of composite iron particles with guar gum encapsulations (Wei Ping Wu et al. 2006).

V. METHOD OF FLUID PREPARATION

Various methods of fluid preparation is used by the different authors by changing the combinations of base fluid, magnetizable particles, and stabilizer additives. Authors have synthesized variety of MR fluid samples based on the application point of view. Summary of materials used by authors is shown in table given below

Table 1 : List of materials used in Magneto rheological fluids

Particle Type	Carrier Fluid	Coating Material	Additives
Iron Oxide(7-8 µm)	Mineral oil	Fumed Silica	Lithium stearate
CarbonylIron(1–6 µm)	Silicone oil	Guar gum	Stearic acid
CarbonylIron(2–4 µm)	Sunflower oil	Xanthan gum	Grease
Iron Nano particles (30-50 nm)	Synthetic oil	Poly vinyl pyrolidone	Honey
Eectrolytic iron	Poly Alfa Olefin		Oleic acid
powder (5-10 µm)	Cotton seed oil		

Authors have used Carrier fluid as a media where the metallic particles are suspended in it. Magnetic particles with magnetorheological effect, are dispersed in the base fluid. Surfactants and additives are utilized to overcome sedimentation problem of heavy particles. High viscosity materials or thixotropic materials such as grease are added to improve stability of particles against sedimentation in magnetorheological fluids (M. Ashtiani , 2014). Procedure followed for preparation is as follows:

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1. Electrolytic iron particles or carbonyl iron were mixed and coated with guar gum or xanthan gum for 50 min at 600 rpm in stirrer.
2. Stearic acid or grease was mixed with silicon oil and stirred for 30 min under 600 rpm using a mechanical stirrer.
3. The electrolytic iron solution was added to silicon oil solution with constant stirring for 2 hours.
4. The MR fluid after preparation was stirred continuously for 8 hours for obtaining a stable solution.

After preparation the Magnetic field strength of fluid shall be from 150 to 250 kA/m with yield stress of 50 to 100 kPa. Voltage applied for the change of rheology is from 1V to 24 V with current from 0 to 2 A and reaction time of current application and change in state of fluid shall be within few milliseconds. Density of the fluid shall be within 4 to 5 gm/cm^3 and working temperature from -50 ^{o}C to 180^{o}C.

VI. Results and Discussions

It is observed from the findings of Wei Ping Wu et.al that carbonyl iron particles coated with gaur gum powder influenced good MR effect of the MR fluid. It is obviously higher than that of the other two kinds of MR fluids without using guar gum coated carbonyl iron particles. Figure 6 shows increase in yield stress of fluid with guar gum coating and no coating. Higher yield stress is the sign of high viscosity of the fluid. Particles with no coating have less yield stress and relatively low viscosity property.

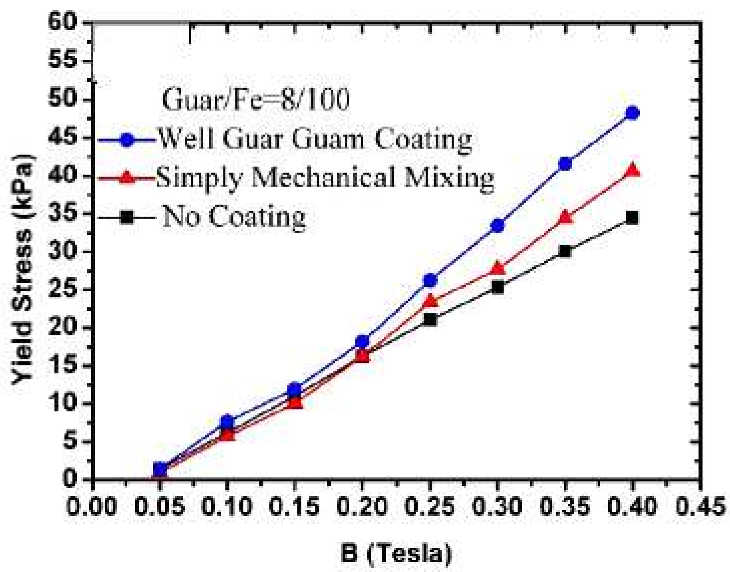

Figure 6. Effect of Guar gum coating on Yield stress of MR Fluid (Wei Ping Wu et al. 2006)

Bhau Kumbhar et al. findings show that the MRF samples with synthetic oil and silicone oil could develop the yield stresses above 70 kPa, while the samples which use sunflower oil as a carrier fluid couldn't exceed 45 kPa. CSi 45% means 45% carbonyl irons are mixed with Silicone oil and CSy 45% means 45% carbonyl ions are mixed with synthetic oil. Su stands for sunflower oil. It is observed from the Figure 7 that the samples with EI powder have found to possess less yield stress as compared to CI powder.

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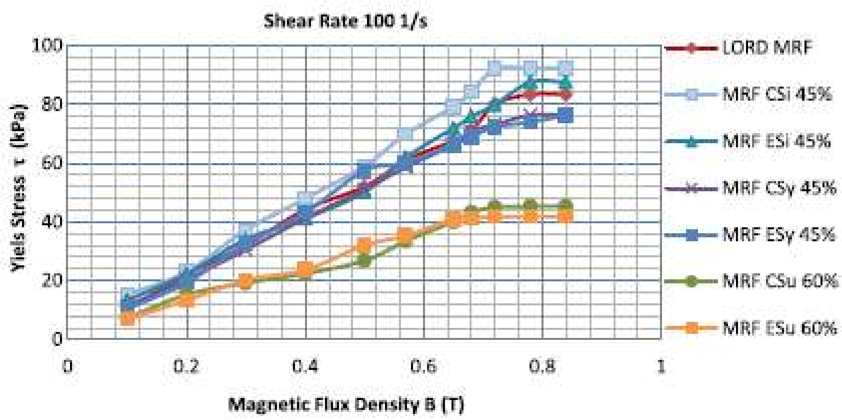

Figure 7. Yield stress of MR fluid with Magnetic Flux Density (Bhau k. Kumbhar et al., 2015)

M. Kciuk et al. explained that sedimentation can be reduced by using fumed silica (Aerosil 200) and therefore to reduce sedimentation Aerosil 200 was added as stabilizers. Figure 8 shows the decrease in

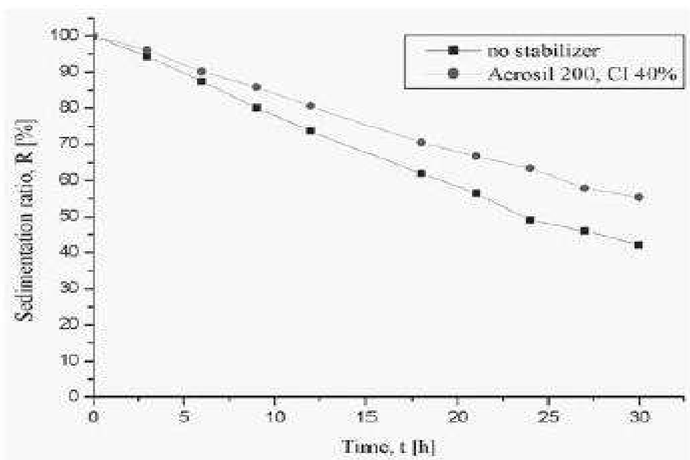

Figure 8. Sedimentation ratio with time (M. Kciuk et al. 2009)

sedimentation with the addition of Aerosil 200 with respect to time. From the sedimentation point of view, both sunflower and cottonseed oil blend-based MR fluid performs superior as observed by Rakesh Jinaga et al. It can be seen that in sunflower blend-based MR fluid the rate of sedimentation is faster than cottonseed blend-based MR fluid.

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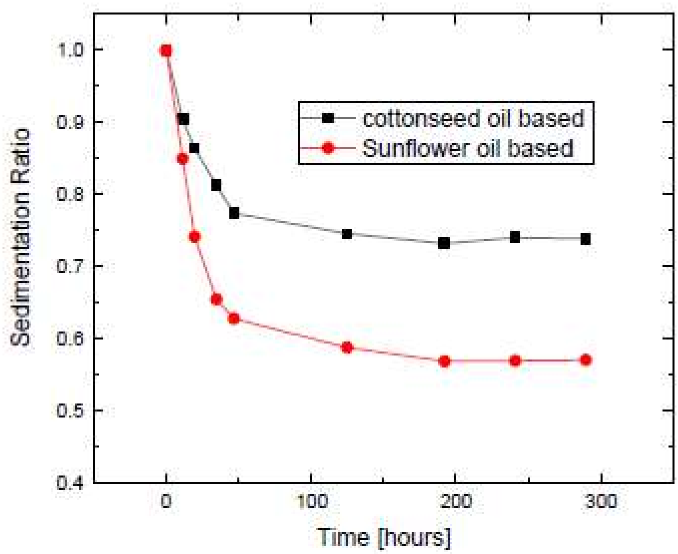

Figure 9. Sedimentation ratio with time (Rakesh Jinaga et al., 2019)

VII. CONCLUSIONS

From investigations of various authors it is observed that sedimentation ratio depends on additives, carrier fluid and density of carrier fluid and iron particles. Density of iron particles shall be as low as possible or it should be less than carrier fluid. Addition of thixotropic materials like guar gum coating increases the yield stress of fluid and also reduces the sedimentation ratio. In other finding sedimentation is reduced by using fumed silica (Aerosil 200), as during on state of magnetic field it avoids agglomeration and reduces sedimentation. It is also reduced by using cottonseed oil as carrier fluid.

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