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Synthesis of Magneto Rheological Fluid

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Abstract*— *Simplicity and more intelligence in its functionality are key features of the Magneto Rheological Fluid (MRF) technology. This technology is an old "newcomers" coming up rapidly on the research and commercial front. In this paper, Magneto Rheological fluid samples are prepared. In this, silicone oil is used as a carrier fluid and is mixed with micron sized iron particles. In order to reduce the sedimentation, white lithium grease is also mixed as an additive in the fluid sample. An experimental setup consisting of an electrical stirrer with speed control unit is designed and developed and fabricated for preparation of the fluid samples. The observations of the surface morphology of iron particles were carried out using digital scanning electron microscope (SEM). The sedimentation properties are studied by visual inspection. The off-state rheological properties e.g. viscosity and shear stress variation with respect to shear rate of the fluid samples are investigated and are measured with a rotational rheometer.

Index Terms*— *Off-State Rheology, Magneto Rheological Fluid, Sedimentation, SEM

I. INTRODUCTION

In the earlier development, most eras of technological development have been connected to utilize and alter the use of materials such as the stone, bronze and iron. The generation of the information technology has stimulated material sciences and led to a new family of engineered materials and structures. Smart materials are the materials that have multiple properties which can be altered or tuned using external fields. The smart materials are designed so that they have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as electric or magnetic fields etc. The smart materials, such as rheological materials exhibit, a perceptible change of a certain physical behavior in reaction to external stimuli. Magneto Rheological Fluid (MRF) is one of the smart materials. Simplicity and more intelligence in its functionality are key features of the Magneto Rheological Fluid (MRF) technology. Excellent feature of this technology e.g. fast response, simple interface between electrical power input and mechanical power output and precise controllability makes the MRF technology attractive for many applications and has also been successfully employed in various low and high volume applications.

An M R Fluid is a suspension of micron-sized magnetically soft particles in a carrier liquid, which exhibit dramatic changes in its rheological properties when subjected to an external magnetic field. The change from a free-flowing liquid state to a solid-like state is reversible and is dependent upon the magnetic field.

Iron powder is the most commonly used particles in the M R Fluid as it has high saturation magnetization. Under the influence of a magnetic field, these iron particles are arranged to form very strong chains of "fluxes" with the pole of one particle being attracted to the opposite pole of another particle. Once aligned, the particles are restrained from moving away from their respective flux lines and act as a barrier preventing the flow of the carrier fluid and thus change its rheological properties.

There are basically three components in an M R Fluid: base fluid, metal particles and stabilizing additives. The base fluid acts as a carrier for the metal particles and naturally combines its lubrication and damping features. For the M R Fluid to have high saturation point, the viscosity of the fluid should be small and almost independent of temperature. In this way the M R effect will be the dominant effect when compared with its natural viscosity. It also varies with temperature and shear stress. In off-state (without magnetic field), M R Fluids behave like base fluids in accordance with its chemical compositions.

Rabinow J. [1] received the first patent for M R Fluid. This invention is related to electro-magnetically controlled torque applying devices between two independently rotatable units. M. R. Jolly et al. [2] discussed the properties and applications of commercial Magneto Rheological Fluids. In this paper, they also explained the effect of component percentage and its effect on the properties like magnetic flux density, yield stress etc. of the fluids. Lord Corporation [3] leading M R devices and M R Fluid manufacturer in the world, has provided information of Magneto Rheological Fluid technology, braking system applications, products, attributes of Magneto Rheological materials, environment and safety concerns. Seval Genc [4] has investigated the on state rheological properties of M R Fluids. He has established the dependency of yield stress on the average particle size and magnetic properties of the particles. M. A. Golden et al. [5] has discussed about the volume fraction of a Magneto Rheological Fluid and its effects on the rheological properties in on and off states. P. P. Phulé [6] discussed about the effect on sedimentation by using large particle size, the viscosity of fluid at zero magnetic field and change in yield stresses when fluid is induced to the magnetic field. J. D. Carlson and K. D. Weiss [7] have introduced alloy particles material that was used as a solid particle instead of the common carbonyl iron. R. T. Foister [8] has discussed about the selection of different components of Magneto Rheological Fluids depending upon the functions, rheology of fluids, effects of different components on rheology of fluid. A. A. Zaman and C. S.

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Dutcher [9] gives the method of obtaining high turn up ratio by using volume fraction of Bimodal particle population with suitable fraction of the small particles and explained that for a fix size of large particles as the size ratio is increased a minimum viscosity occurs at a higher volume ratio of the small particles. N. M. Wereley et al. [10] discussed about the Bi-disperse Magneto Rheological Fluids using Fe Particles at Nano and Micron Scale, in order to produce more efficient packing structure of small particles. Mark R. Jolly et al. [11] has discussed the rheological and magnetic properties of several Magneto Rheological Fluids. These fluids are compared using appropriate Figure of Merit based on conventional design paradigm.

The primary focus of this work is to develop synthesis and characterize Magneto Rheological Fluid. These fluids may then conform to the demands of the users and satisfy different requirements under a variety of external conditions.

II. SYNTHESIS OF MAGNETO RHEOLOGICAL FLUID SAMPLE

A severe limitation of commercially available Magneto Rheological Fluids for its industrial application is its high cost ($ 800/ liter). Moreover there is only one firm in the world i.e. Lord Corp. USA, that supplies M R Fluid for research and allied work all over the world. Hence, the primary focuses of this work is to develop and synthesis Magneto Rheological Fluid.

A. Components of Magneto Rheological fluid

The Magneto Rheological Fluids are made up of three main components i.e. the dispersed phase (the magnetizable particles), the continuous phase (the carrier liquid) and the additives or stabilizers.

A magnetically active dispersed phase is the main source for the strength of an M R Fluid. The best particles for the M R Fluid are alloys of iron and cobalt that have saturation magnetization of about 2.4 Tesla. Unfortunately, such alloys are expensive for most practical applications. The next best practical particles for the fluid are simply pure iron, as they have a saturation magnetization of 2.15 Tesla. After market and literature survey, pure iron particle size of 300 mesh size is selected and used for the synthesis of Magneto Rheological Fluid samples.

The primary function of the carrier liquid is to provide a low permeability and non magnetic base liquid in which the magnetically active phase particles remain suspended. The liquid has to posses low permeable in order to allow the particles to polarize with the utmost effectiveness. It, thus, enhances the Magneto Rheological effect. Examples of appropriate carrier liquid include silicone oils, mineral oils, paraffin oils etc. The silicone oil is most frequently used carrier liquid after hydrocarbon oil. In order to keep the off-state viscosity low, silicone oil with viscosity 100 cSt (which corresponds to 0.96 Pa-s dynamic viscosity), is used for synthesis of the M R Fluids samples.

Additives form the third component of the Magneto Rheological Fluid and are used in the fluids for many purposes, e.g. prevention and minimization of sedimentation, prevention and minimization of coagulating of the particles, maintain a coating on the particles in order to enhance re-dispersibililty and to enhance anti-oxidation. The prevention of sedimentation is one of the most important aspects. For the practical reason, the sedimentation rate is to be kept at minimum possible level. White lithium grease is a good additive with carrier liquid silicone oil [3]. This white lithium grease is used in many automotive applications and easily available in automobile spare part shops. White lithium grease is thus used as an additive for the sample.

A.1 Requirements for preparation of M R fluid samples

Magneto Rheological Fluids have been prepared in the Semi-Active Vibration Control Laboratory of the Mechanical Engineering Department using the above mentioned materials as its main constituents. While preparing the fluid samples, additional apparatus/equipments and other safety items e.g. latex gloves, paper towels, electronic weighing machine, sieve, stainless steel container, air tight plastic containers, electrical stirrer etc are used.

A.2 Electrical stirrer

For the preparation of Magneto Rheological Fluid samples, an electrical stirrer is designed and fabricated and is shown in Fig. 1. The stirrer has controllable speed, as the fluid constituents need to be stirred between 400 to 1000 rpm [12].

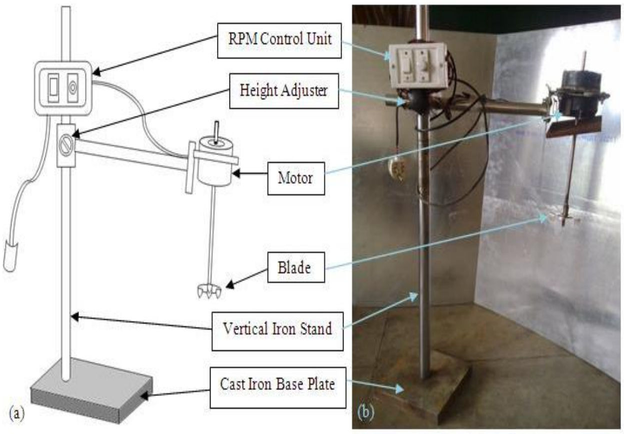


Fig. 1 (a) Shows the schematic diagram of stirrer and (b) Shows the actual photograph of the designed stirrer

A.3 Preparation of Magneto Rheological fluid samples

To prepare the M R Fluid samples, the material composition is fixed. From the literature survey, it is found that there are two methods by which the constituents of the M R Fluid are selected (i) volume percentage and (ii) weight percentage [13 & 14]. In this work, the constituents are used as per the weight percentage. Four samples are prepared by using different weights of M R Fluid constituents. Two levels for each constituent are fixed and thus the four combinations are selected to represent it's inter-effect on its properties. The levels fixed for preparing these four samples are shown in Table 1.

Table 1Composition of constituents used and their weight percentage

Sample Name	Fe Particle (gm)	Silicone oil (gm)	Grease (gm)	wt. % of materials wrt whole fluid weight		
				Fe Particle	Silicone oil	Grease
MRF1	200	112.5	8.75	62.26	35.02	2.72
MRF2	200	133	12	57.97	38.55	3.48

MRF3	220	112.5	12	63.86	32.66	3.48
MRF4	220	133	8.75	60.82	36.76	2.42

According to the above four combinations, the Magneto Rheological Fluid samples are prepared. A fluid, thus, prepared, looks like a black color continuous fluid which appears similar to black liquid paint. This prepared fluid is the Magneto Rheological Fluid.

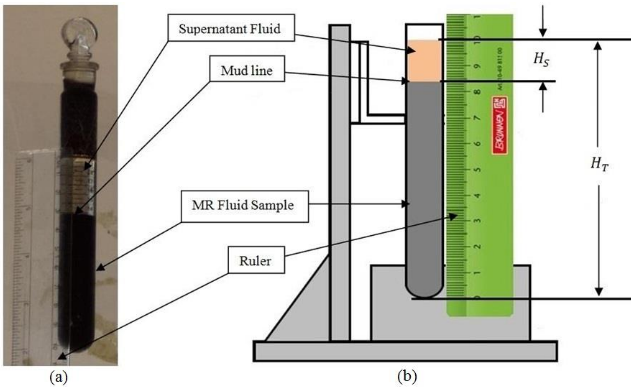
III. TESTING AND RESULT OF MAGNETO RHEOLOGICAL FLUID SAMPLES

A. Sedimentation rate

Sedimentation is the tendency of the particles in suspension to settle down in the fluid in which they are entrained and come to rest against a barrier. This is due to their motion through the fluid in response to the forces acting on them. These forces may be due to gravity, centrifugal acceleration or electromagnetism.

The sedimentation of particles, in the M R Fluid, is determined by neglecting the magnetic effect on the M R Fluid particles. The inherent density difference of the carrier fluid and the iron particles results in the sedimentation of the particles, leaving an upper volume as supernatant fluid (the clarified fluid above the mud line). The upper mud line is the boundary between the supernatant fluid and turbid part of carrier oil. The sedimentation of particles is measured by visually observing the position change of the mud line.

For analyzing the sedimentation of the Magneto Rheological Fluid samples, a setup is used and is shown in Fig. 2. This set up contains a tube holding device and a ruler which is placed adjacent to the test tube to measure the height of supernatant fluid. With passage of time, the height of supernatant fluid increases and the height of turbid part decreases.



(a) (b)

Fig. 2 **(a)** Sedimentation measurement in actual experiment and **(b)** Schematic diagram of the setup used to determine sedimentation ratio

The sedimentation is observed visually at day time to get a clear view of the observation being made for the height of supernatant and the turbid part of the M R Fluid sample. Prepared samples were filled up to 10 cm in a cylindrical glass test tube for few hours at vertical stationary position. The height of the supernatant fluid (H_s) is measured after every 5 minutes with the help of ruler and stop watch. Thus, sedimentation ratio (S_R) is calculated. The sedimentation ratio is defined as the ratio of the height of the supernatant oil to the total height of the M R Fluid filled and is given as

$$S_R = \frac{H_S}{H_T} \times 100\ \% \quad (1)$$

Where, S_R is the sedimentation ratio, H_S is the height of supernatant fluid and H_T is the total height of fluid filled in the tube.

Figure 3 shows the sedimentation ratio of iron particles with different additives percentage in the M R Fluid sample (Table 1). Higher content of iron particles have positive impact on Magneto Rheological effect. From the above graph (Fig. 3), it can be observed that MRF4 sample has faster sedimentation ratio in the beginning of experiment, leaving small percentage of iron particle suspended in the supernatant fluid and then have lesser sedimentation ratio later on. In the MRF4 sample, the grease content is 8.75 gm against 220 gm of iron particle (Table 1) i.e. 2.42% of grease of the sample weight. The MRF2 sample is giving the lesser sedimentation ratio in the beginning of experiment and have still lesser sedimentation ratio later on. In MRF2 sample the grease content is 12 gm against 200 gm of iron particle (Table 1) i.e. 3.48% of sample weight. From the above it can be concluded that the grease has an influence on the sedimentation ratio of the Magneto Rheological Fluids. The sedimentation decreases by adding higher percentage of grease (additives). It implies that increase in the percentage of additives increases the stability of the M R Fluid

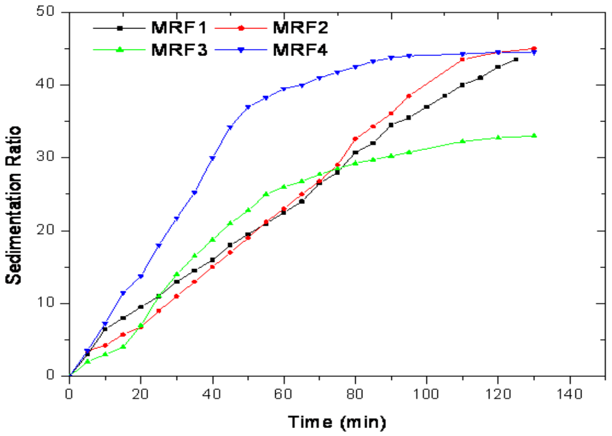


Fig 3 Sedimentation curves of all four fluids samples

B. Off-state rheology testing

Rheology is defined as a study of the flow properties and the behavior of materials or the response of materials to applied stress. The desired viscosity of the M R Fluids is to be minimum in the off-state condition, while in the on-state condition, the yield stress of the fluid be the maximum. Both off-state viscosity and the on-state yield stress are very important in order to achieve a good M R effect. Turn-up ratio is defined as the ratio of the force output (on-state controlled by yield stress) generated by the magnetically activated M R Fluid divided by the force output (off-state controlled by viscosity) for the same fluid in the off-state. Basically, it refers to the differences between off-state viscosity and on-state yield stress. As mentioned earlier, the increases in the volume fraction of the particle increases the yield stress and viscosity of the M R fluids. The on and off-states of M R Fluids have been linked together in the sense that any attempt to maximize the on-state yield stress by increasing the solid iron particle fraction, carry a great penalty in the turn-up ratio as the viscosity in the off-state also increase at the same time.

Thus, in order to obtain a suitably high yield stress, one must tolerate a relatively high viscosity in the off-state condition.

A rheometer is the instrument used to measure a material's rheological properties. It is based on the principle of a viscometer. The testing of the prepared M R Fluid samples, for its off state properties, is made at Anton Paar office, Phase-5, Udhyog Vihar, Gurgaon.

Shear stress-shear strain and shear stress-dynamic viscosity data for all four M R Fluid samples are determined in the experimentation. The fluids before testing is stirred properly with a spatula and then filled into the measuring cylinder of the machine. To make the M R Fluid samples more homogenous further stirring is done on the rheometer itself for 60 seconds. The M R Fluid of 19 ml volume is used in testing of one sample.

The behavior of the fluid samples is determined by obtaining 50 data points at a time interval of 2 second at a constant temperature of 25ºC on the rheometer. Figure 4 shows the experimental data for shear stress (Pa) at different shear rate (s^{-1}) for the four fluid samples.

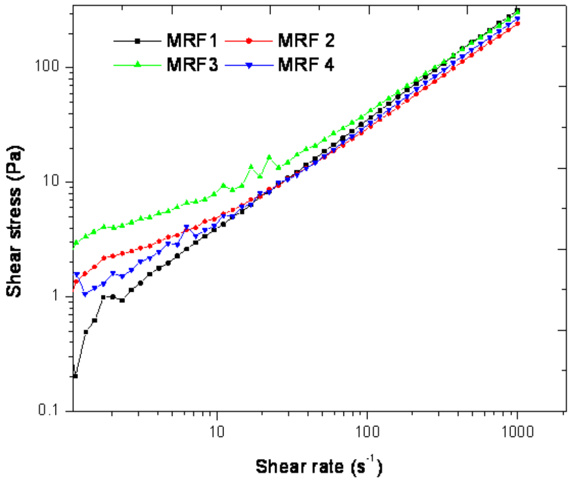


Fig. 4 Shear rate v/s shear stress for MRF1, MRF2, MRF3, and MRF4 fluid samples

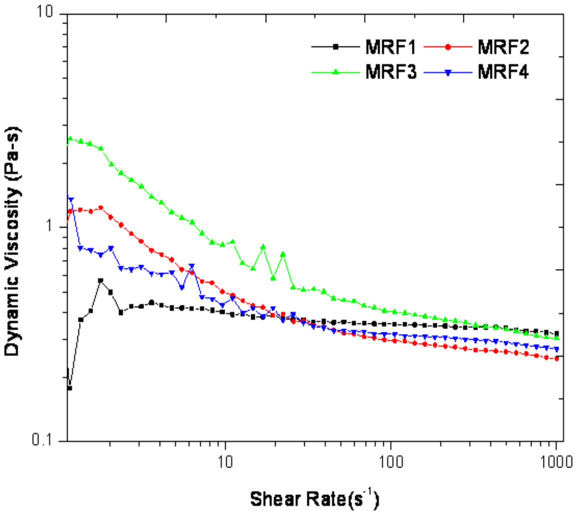


Fig. 5 Shear rate v/s dynamic viscosity for MRF1, MRF2, MRF3, and MRF4 fluid samples

The graph (Fig. 4) shows Non-Newtonian fluid behavior for the M R fluid samples in the absence of magnetic field and shear stress increases with increase in shear rate. The graph also shows that the M R Fluid samples are following Bingham Plastic Modal. At low shear rate, the MRF3 sample is showing the higher shear stress. It is because of the presence of highest percentage of iron particles in the least percentage of silicone oil among the four samples. At the higher shear rate, all the fluid samples shows almost same behavior of shear stress.

The Fig. 5 shows the experimental data, on log-log scale, of dynamic viscosity (Pa-S) with respect to shear rate (s^{-1}) in the experimentation. It is observed in Fig. 5 that viscosity of all the M R Fluid samples decreases with increase in shear rate. At low shear rate, the viscosity of MRF3 sample is greater than other samples. It is because of the presence of highest percentage of iron particles in the least percentage of silicone oil among the four samples. With increase in shear rate the viscosity decreases and at high shear rate viscosity varies from 0.244 to 0.32 Pa-s for all four fluid samples. At higher shear rate, the viscosity of MRF1 sample is 0.32 Pa-s while viscosity of MRF2 sample is 0.244 Pa-s. A shear thinning behavior of the M R suspension is also observed. Shear thinning effect is minimal for the MRF1 sample over a wide range of shear rate.

C. SEM and optical scanning

Fig. 6 Optical image of M R Fluid observed in Optical Scanning Microscope

The prepared M R Fluid samples are observed under Optical Scanning Microscope and Scanning Electron Microscope (SEM) for the determination of average size of the iron particles suspended in the fluid. The samples are observed at different magnifications factors. The optical images and SEM of the fluid samples is taken at National Institute of Pharmaceutical Education and Research (NIPER), Mohali, Punjab on Hitachi S-3400N SEM. Figure 6 shows the optical image of the M R Fluid sample observed by Optical Scanning Microscope. The fluid samples are also observed through Scanning Electron Microscope (SEM) at NIPER, Mohali with different magnifications to determine the average size of iron particles in the fluid sample.

Figure 7 shows the iron particles suspended in silicon oil (as carrier fluid) observed in Scanning Electron Microscope. The data analysis refers to prepared samples of the Magneto-Rheological Fluid. The iron particles have found to be of irregular shapes. The average size of iron particles is found to be about 24.7 µm.

IV. CONCLUSIONS

Better understanding of M R Fluid characteristics is an important aspect for focusing studies on engineering based issues, optimizing apparatus geometry, magnetic field distribution, developing predictive capabilities for control strategies.

In this paper, different samples of M R Fluid containing different weight composition of its constituents were prepared. The two levels for each of the M R Fluid constituent are fixed. Four samples are prepared using different combinations of selected constituent levels. These samples have been analyzed and tested for its sedimentation and the rheological properties in off-state condition. The average particle size of iron powder is studied and is observed by SEM at NIPER, Mohali. It is found to be 24.7 µm. The four samples are also analyzed for the sedimentation ratio. It is found that the weight composition of grease affect the sedimentation ratio. Higher the weight of grease results lower sedimentation ratio and vice-versa. It implies that an increase in percentage of grease (additives) provides the better stability to M R Fluid. Anton Paar, Gurgaon facilities are used to analyze and investigate the off-state rheological properties of the M R Fluid samples. The relationship between shear stress & shear rate and variation of viscosity with shear rate for these samples were determined. It is observed that the viscosity of every sample decreases with increase in shear rate. The shear thinning behavior is observed from the viscosity-shear rate data.

In this article, a stable Magneto-Rheological Fluids have been formulated using in-house technology, at a fraction of cost of which they are available commercially and analyzed for its sedimentation and off state rheological properties. These fluid may be used in possible applications which requires sudden controlled damping (yield stress), and especially in the also experimental studies.

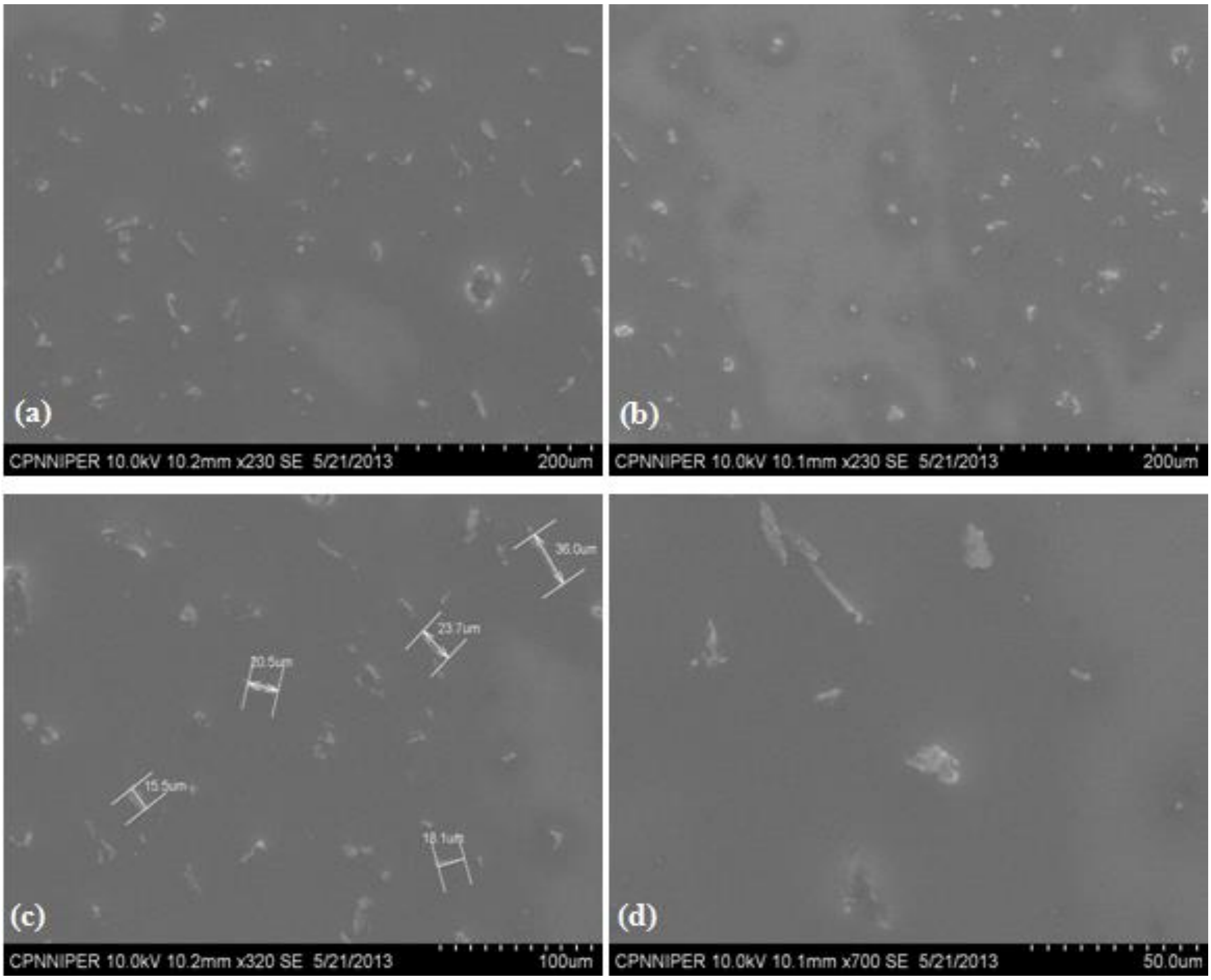


Fig. 7 Scanning Electron Microscopic images of M R Fluid sample (a) at 230 times magnification of one portion; (b) at 230 times magnification of another portion; (c) at 320 times magnification and (d) at 700 times magnification

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