TRIBOLOGICAL BEHAVIOUR OF MAGNETORHEOLOGICAL FLUID SEDIMENTATION STABILITY

PROJECT REPORT SUBMITTED BY

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Under the guidance of

MR. SANDEEP O S
Assistant Professor, Department of Mechanical Engineering

In partial fulfilment of the requirements
For the award of the degree of

BACHELOR OF TECHNOLOGY

in

MECHANICAL ENGINEERING
(NBA ACCREDITED)

The APJ Abdul Kalam Technological University

Adi Shankara Institute of
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Certified that this is a bonafide record of the project entitled

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Submitted by

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during the year 2020-21 in partial fulfilment of the requirement for the award of the degree of

Bachelor of Technology in mechanical Engineering

Internal Supervisor   Head of the Department

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ABSTRACT

Magneto-rheological (MR) fluid technology has been proven for many industrial applications like dampers, actuators, etc. MR fluid is a smart material whose rheological characteristics change rapidly and can be controlled easily in presence of an applied magnetic field. MR damper is a device which transmits force or vibration by increasing viscosity of MR fluid. In this research, an effort has been made to synthesize MR fluid samples which will typically meet the requirements of MR damper applications. In this study, various additives and carbonyl iron powder-based MR fluids have been synthesized by using gaur gum, citric acid and PEG 600 powder as a surface coating to reduce agglomeration of the MR fluid. MR fluid samples based on Silicon oil, which is non-bio-degradable and abundantly available have also been used. These MR fluid samples are characterized for determination of magnetic, morphological and rheological properties. This study helps identify most suitable localized MR fluid meant for MR damper application.

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LIST OF ABBREVIATIONS

ABBREVIATION	EXPLANATION
MR	Magnetorheological
MRF	Magnetorheological Fluid
SEM	Scanning Electron Microscopy
DMR	Dimorphic Magnetorheological
CI	Carbonyl Iron
ER	Electro Rheological

CHAPTER 1

INTRODUCTION

MRF belongs to one of the smart materials featuring the magnetic field-dependent rheological properties and hence, control performance of various application systems in which MR fluid is used as carrier fluid medium can be achieved by simply controlling the magnitude of the field intensity. More specifically, MR fluid behaves like a Newtonian fluid (fluid-like phase) in the absence of the magnetic field, but its behaviour rapidly changes to the non-Newtonian fluid (solid-like phase) by applying the magnetic field. This special characteristic of MR fluid can provide a quiet, simple, and rapid-response interface between electronic controls and mechanical systems.

Magnetorheological (MR) fluid is a type of classical smart materials, which consist of stable suspensions of micro sized magnetically polarizable particles such as carbonyl iron (CI), carrier liquid such as silicone oil. The rheological properties of MR fluid are instantaneously changed by applying a magnetic field.

The MR particles aggregate into fibrous columns, which are perpendicular in the direction of magnetic field. Then, since energy is required to deform and rupture the chains, this microstructural transition is responsible for the onset of a large, "tuneable" finite yield stress. Yield stress depends on the magnitude of the applied magnetic field. The magnetic field controls the level of the MR effect. The yield stress can be varied depending on applied magnetic field and particle concentration. Until now, MR fluids and other smart materials of electrorheological (ER) fluids are primarily limited to semi-active devices. In general, the yield stresses obtained with MR fluids are usually much larger than those obtained with ER fluids because of larger magneto static energy. Also, dynamic yield strength and operating temperature range of MR fluids has changed greatly.

MR fluid is applied to various industrial fields of automobile area, aerospace area, manufacturing, etc. In addition, MR fluid can be applied to any industrial area where lubricant is used. Applications and economic benefits of MR fluid technology continue to be extensive and considerable. Therefore, proprietary technology for commercial MR fluids should be secured. Thus, the stability and performance improvement of the MR fluid become more and more important for study.

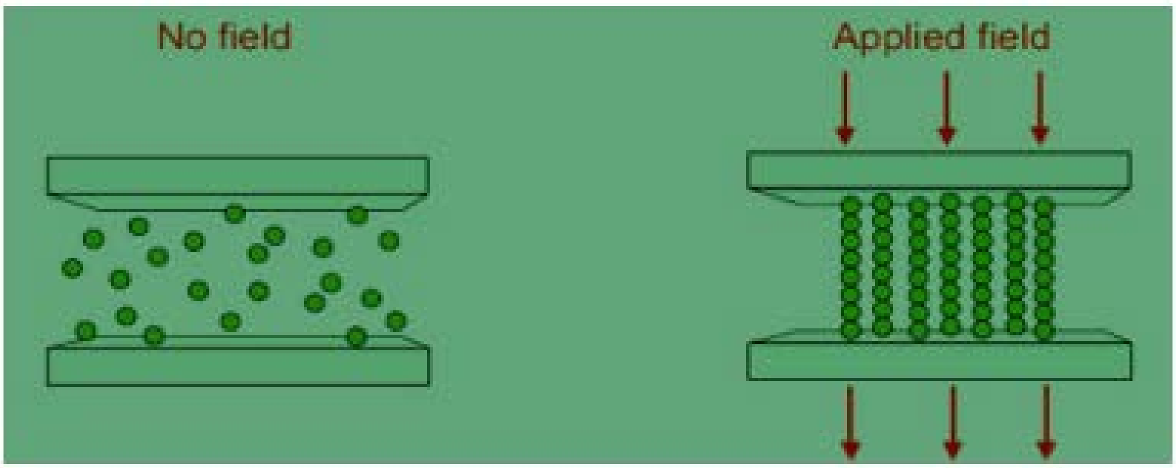


Fig 1.1 Chain like structure formation

1.1 PROBLEM DEFINITION AND SCOPE OF THE WORK

The challenges in the preparation and use of magnetorheological fluids that include incrustation, sedimentation, agglomeration, and also oxidation of the particles. The results showed an improvement in the reduction of sedimentation and other problems decreasing comparatively. Experiments were carried out to establish the sedimentation rates for compositions with varying fractions of additives.

Temperature effects on magnetorheological fluids have caused alteration in viscosity as the latter dependent on temperature. The operating temperature for magnetorheological fluids may range from − 20 °C to 150 °C depending on the application.

Magneto rheological liquid finds expanding use in vehicle suspension frameworks. The item should observe inescapable reception in car dampeners inside the following 10 to 20 years. Magneto-rheological fluids are progressively being utilized in a variety of utilizations, including advanced mechanics, aviation, military and protection, electrical and hardware, building and development, and car, among others which will make rewarding open doors for the market

CHAPTER 2

LITERATURE SURVEY

1) "**Material Characterization of Magnetorheological Fluid Subjected to Long-Term Operation in Damper**" (2018) by Dewi Uthami and Ubaidullah. Here the research is to investigates the field-dependent rheological properties of magnetorheological (MR) fluid used to fill in MR dampers after long-term cyclic operation.

2) "**Tribological Characteristics Modification of Magnetorheological Fluid**" (2016) by Won Oh Cho Hyuk and Chae Yun made modification of MR fluid, which is modified by adding certain additives, is attempted to improve tribological performance, the microscopic changes of surfaces and MR particles are investigated by using scanning electron microscopy (SEM).

3) "**Preparation of Magnetorheological Fluid and Study on Its Rheological Properties**" (2014) by Shreedhar Kolekar. The present paper focuses on preparation and process of the magnetorheological (MR) fluid whose carrier fluid is silicone-based oil and its additive is the commercial grease with different concentration of iron particles. The result shows that shear stress as a function of magnetic flux density and viscosity does not strictly scale with iron loading.

4) "**Synthesis and Characterization of Mr Fluid for Damper in Vehicle Suspension System**" (2017) by Akshay Inamdar and Muzammil Inamdar have done focuses on the calculation of sedimentation ratio of different MR fluids using different carrier fluids and nanoparticles or micro particles or mixture of both. This work was further extended to design and testing of MR damper for vehicle suspension system.

5) "**Preparation and Study of Characteristics of Iron Based MR Fluids**" (2018) investigated by A.B.Muddebihala and S.F.Patilb carry out to identify the characteristics of prepared Magnetorheological fluid (MRF) fluids, composed of iron particles and analyse

their flow behaviour in terms of the stability and MR properties. MR fluids are prepared using silicone oil and sunflower oil, mixed with iron powder.

6) "**Methods for sedimentation study of magnetorheological fluid**" (2019) investigated by Hiren Prajapati and Jas Shahanand, deals with test stability of MRF because unstable MRF no longer give rheological response. The methods for sedimentation study of magnetorheological fluids are Visual inspection, UV spectroscopy and Laser beam deflection.

7) "**Particle Sedimentation in Magnetorheological Fluid and its effect**" (2017) by Takehito Kikuchi investigated the effect of the sedimentation in the mechanical properties of the MRFs. The yield stresses of a MRF are decreased by 30 % after the sedimentation.

8) "**Preparation and characterization of magnetorheological fluid for damper application**" (2016) by N. P. Sherje and Dr. S. V. Deshmukh, the work includes preparation of MR fluid using different carrier fluids and additives and study effect of particle size, type and amount of additives and viscosity on stability of fluid.

9) "**The enhanced MR performance of dimorphic MR suspensions containing either magnetic rods or their non-magnetic analogs**" (2017) investigated by Tomas Plachy, Martin Cvek. Controlled shear rate mode experiments were performed using a rotational rheometer with a source of an external magnetic field in order to investigate their MR behaviour. Moreover, the properties of the novel prepared dimorphic MR (DMR) suspensions were compared with conventional MR suspensions based on spherical CI micro particles.

CHAPTER 3

MATERIALS AND METHODOLOGY

The major chemicals that are effectively employed in the preparation and the testing of the 5 MR fluids are described below: -

3.1 BASE OILS AND ADDITIVES

3.1.1 CARRIER FLUID

Carrier fluids are selected based on their intrinsic viscosity, temperature stability and compatibility with other materials of the device. The most common carrier fluids are hydrocarbon oils, which can either be mineral oils or synthetic oils because of their good lubrication, durability and the availability of a large range of additives, **Silicone oils** can be used instead in order to achieve a broader operating temperature range or due to compatibility issues with other materials of the device. The properties of silicon oil taken for study are: -

- Kinematic Viscosity- 1000cst
- Wt/ml at 25 °C = 0.970g
- Refractive index at 25 °C= 1.403
- Thermal stability ranges of 100-250°C

3.1.2 ADDITIVES

Many types of additives, often proprietary, are used in MR-fluid formulations. They have many purposes such as: inhibiting particle settling and agglomeration, reducing friction, and preventing particle oxidation and wear. The major impact of these properties on the MR-fluid stability and durability, which are crucial in industrial applications. The main additives taken are: -

- Gum Arabic

- Nickel-Zinc powder
- Silicon carbide
- Arabic gum

3.1.3 SURFACTANTS

- Citric Acid
- Guar Gum
- PEG 6000
- Guar gum

Typical MR fluids are the suspensions of micron sized, magnetisable particles (mainly iron) in an appropriate carrier liquid. Typically, the diameter of the magnetisable particles range from 3 to 5 microns. Functional MR fluids may be made with larger particles; however, stable suspension of particles becomes increasingly more difficult as the size increases. Thus, **Fe Particles** with size of 5 microns is used as nanoparticles.

3.2 EQUIPMENT USED

3.2.1 ULTRASONIC PROBE

The ultrasonic probe, Vibra-Cell VCX750, is used to thoroughly mix the additives with base oil. The ultrasonic power supply (generator) converts 50/60 Hz voltage to high frequency electrical energy. This alternating voltage is applied to disc-shaped ceramic piezoelectric crystals within the converter, causing them to expand and contract with each change of polarity. These high-frequency longitudinal mechanical vibrations are amplified by the probe (horn) and transmitted into the liquid as alternating expansive and compressive acoustic pressure waves. The pressure fluctuations cause the liquid molecule cohesive forces to break down, pulling apart the liquid and creating millions of microbubbles (cavities), which expand during the low-pressure phases, and implode violently during the high-pressure phases. As the bubbles collapse, millions of microscopic shock waves, micro jet streams, eddies and extremes in pressures and temperatures are generated at the implosion sites and propagated to the surrounding medium. Although this phenomenon, known as cavitation, lasts but a few microseconds, and the amount of energy released by each individual bubble is minimal, the cumulative amount of energy generated by the imploding cavities is extremely high and many times that generated in an ultrasonic bath.

Fig 3.2.1.1 Ultrasonic Probe

3.2.2 DIGITAL WEIGHING BALANCE

For preparing vegetable lubricating oil with additives in required proportions, weight of these items should be accurate as the quantity produced is low. For measuring accurate quantities, Schimadzu AUY 220 digital weighing balance (figure 3.6) is used, which can measure up to an accuracy of 0.0001g.

Fig 3.2.2.1 Digital Weighing Balance

This weighing balance is very useful while mixing various proportions of the additives with base oil. Measurements are carried out in an air conditions room and the glass slide doors of the equipment are to be closed while taking the readings. The specifications of the Schimadzu AUY 220 digital weighing balance are given below.

Table 3.2.2.2 Schimadzu AUY 220 digital weighing balance specifications

Capacity	220 g
Minimum Display	0.1 mg
Repeatability	≤0.1 mg
Linearity	±0.2 mg
Response time	3 second
Operation temperature range	5°C to 40°C
Main body Dimension	220 mm ×330 mm×310 mm
Altitude	upto 2000 m

3.2.3 BROOKFIELD VISCOMETER

The viscosity of the lubricating oil is measured at different temperature is measured with Brookfield LVDV2T viscometer made by Brookfield Corporation, USA. Total control of instrument and test parameters are automatically controlled and data are collected with Rheocalc-T software and a dedicated computer.

Fig 3.2.3.1 Brookfield LV DV2T Extra Viscometer

Rheocalc-T can analyse data, generate multiple plot overlays, print tabular data, run math models and perform other time saving routines. Up to five comparison data sets can be plotted and saved.

Table 3.2.3.2 Brookfield LV DV2T Extra Viscometer specifications

Speed	Interleabed: LV/RV (18 speeds)
Sequential	LV/RV 18 speeds
Custom	54 speeds, user selectable
Weight	
Gross weight	10.5 kg
net weight	9 kg
Carton volume	0.05 m^3
Temperature sensing range	-100°C to 300°C
Analog torque output	0 to 1 V DC (0 to 100% torque)
Analog Temperature output	0 to 4 V DC (10 mV/°C)
Viscosity accuracy	±1% of full scale range
Viscosity repeatability	±1%
temperature accuracy	±1°C : -100°C to +149 °C ±2°C : +150°C to 300°C

CHAPTER 4

PREPARATION OF MR FLUID

MR fluid can be prepared in the laboratory by using mineral oil, esterizes fatty acid or suitable organic liquid. Here in this research work, MR fluid is prepared by using low viscosity oil like silicone oil taken for the preparation along with iron powder, additives and surfactants. The composition of MR fluid in 5 different compositions for preparation is calculated as shown in Table 4.

TABLE 4 Composition

SI. No.	Carrier Fluid	Fe Particle [Wt]	Additives		Surfactant	
			Type	[Wt of CI]	Type	[Wt of CI]
MR 1	50 ml	25 gm	Arabic Gum	8 gm	Citric Acid	12 gm
MR 2	40 ml	35 gm	Nickel Zinc Powder	12 gm	Guar Gum	9 gm
MR 3	30 ml	22 gm	Arabic Gum	6 gm	Citric Acid	8 gm
MR 4	30 ml	30 gm	Silicon Carbide	12 gm	PEG 6000	8 gm
MR 5	50 ml	38 gm	Arabic Gum	14 gm	Guar Gum	9 gm

4.1 Preparation of MR fluid

The silicone oil is first mixed with additives, which is a very small concentration, using an electric stirrer. This mixing process is done for 1 h continuously till it is seen that the grease particles are dissolved and suspended in the silicone oil. It appears to be a dark kind of solution now. After the mixing is complete it is noticed that the particles are suspended in the silicone oil, this in turn helps in the suspension of the iron powder which if not done will settle to the bottom in course of time. The Fig. shows the additives and surfactants mixed with silicone oil.

After the solution is prepared as seen above, the required weighed iron powder is then poured into it in parts while the stirring is carried out. As the iron powder falls into the container it gets mixed along with the solution and becomes highly viscous and appears to be black in colour. After the entire amount is poured into the silicone additive solution, it is stirred for a while so that uniform and proper mixing of the solution is done. This stirring is carried out for about an hour and the end result obtained is MR fluid as shown in Fig 4.1.1-5

Fig.4.1.1 MR 1

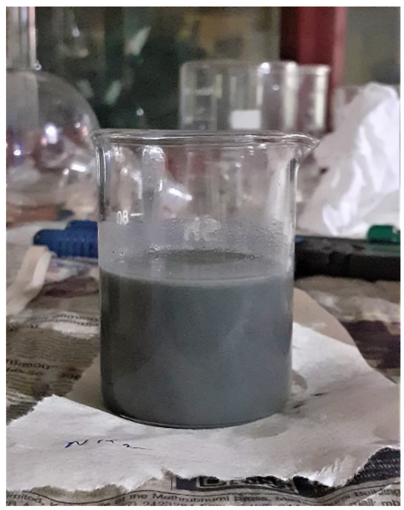


Fig.4.1.2 MR 2

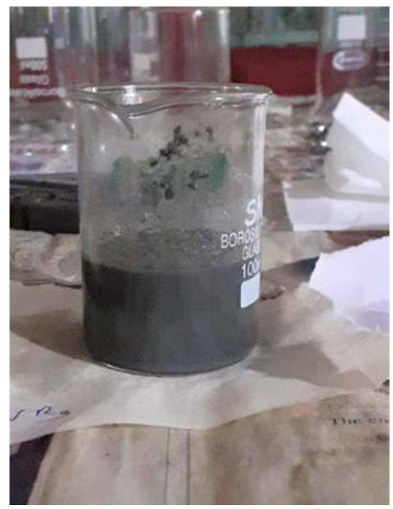


Fig.4.1.3 MR 3

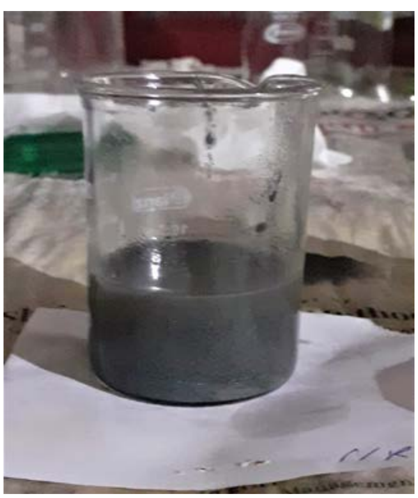


Fig.4.1.4 MR 4

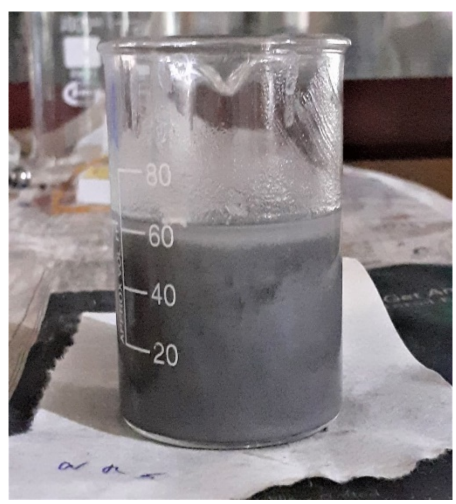


Fig.4.1.5 MR 5

CHAPTER 5

EXPERIMENTS ON MRF

5.1 MEASUREMENT OF VISCOSITY

The Brookfield LV DV2T viscometer measures fluid viscosity at given shear rates. The principle of operation of the viscometer is to rotate a spindle which is immersed in the test fluid through a calibrated spring. The viscous drag of the fluid against the spindle is measured by the spring deflection. Spring deflection is measured with a rotary transducer which provides a torque signal. The measurement range of a LVDV2T viscometer is determined by the rotational speed of the spindle, the size and shape of the spindle, the container in which the spindle is rotating, and the full-scale torque of the calibrated spring. Viscosity appears in units of centipoises in digital display of viscometer.

Viscometers are provided with a set of four spindles. The spindles are attached to the viscometer by screwing them to the male coupling nut. The lower shaft should be held in one hand (lifted slightly), and the spindle screwed to the left. The face of the spindle nut and the matching surface on the coupling nut shaft should be smooth and clean to prevent eccentric rotation of the spindle. Spindles can be identified by the number on the side of the spindle coupling nut. The LVDV2T must have a spindle entry code number to calculate viscosity values. Setting the speed/spindle switch to the right position will allow the operator to adjust the spindle selection. The select knob can be rotated until the desired spindle number is selected. Once the desired spindle number is shown on the display, set the spindle/speed. There are 18 rotational speeds available on the LVDV2T viscometer. Setting the speed/spindle switch in the left position will allow the operator to adjust the speed selection. The select knob can be rotated until the desired speed is selected.

5.2 MEASUREMENT OF SEDIMENTATION RATIO

The sedimentation ratio, every sample is kept into cylindrical glass beaker and observed after every 5 hrs the change in boundary of clear and turbid part of fluid. The observation is continued till 50 Hrs and calculated the sedimentation ratio by using a simple relation given below.

$$R = \frac{x}{x+y} \times 100\%$$

Where, x= length of clear part, y= length of turbid part

The figure 5.2.1 show the final sedimented state of MRF samples.

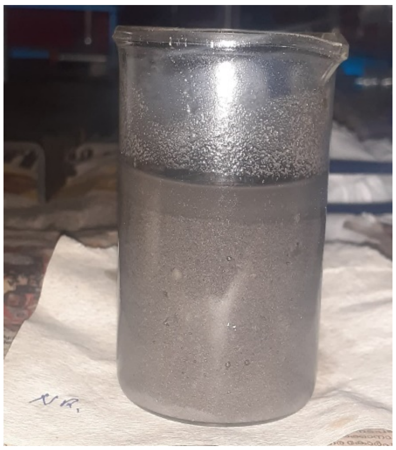


Fig.5.2.1 MR 1

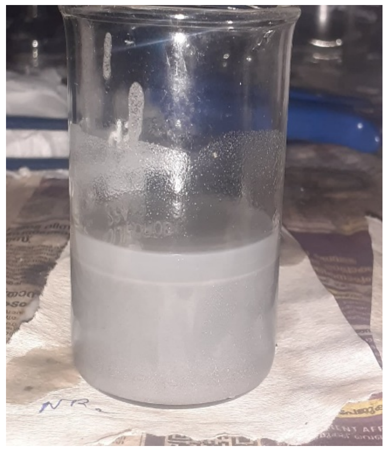


Fig.5.2.2 MR 2

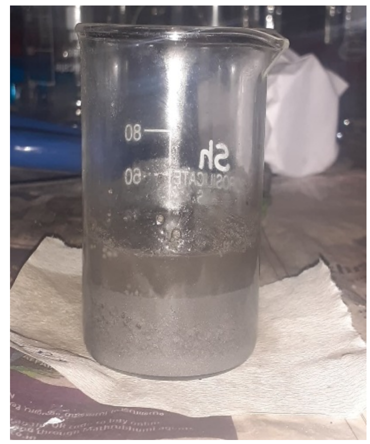


Fig.5.2.3 MR 3

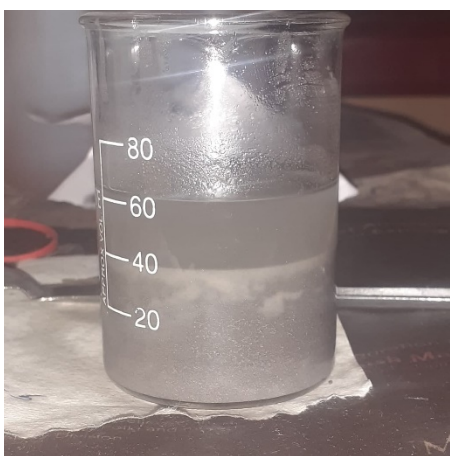


Fig.5.2.4 MR 4

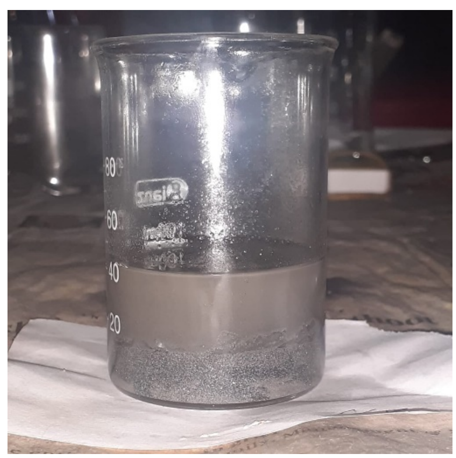
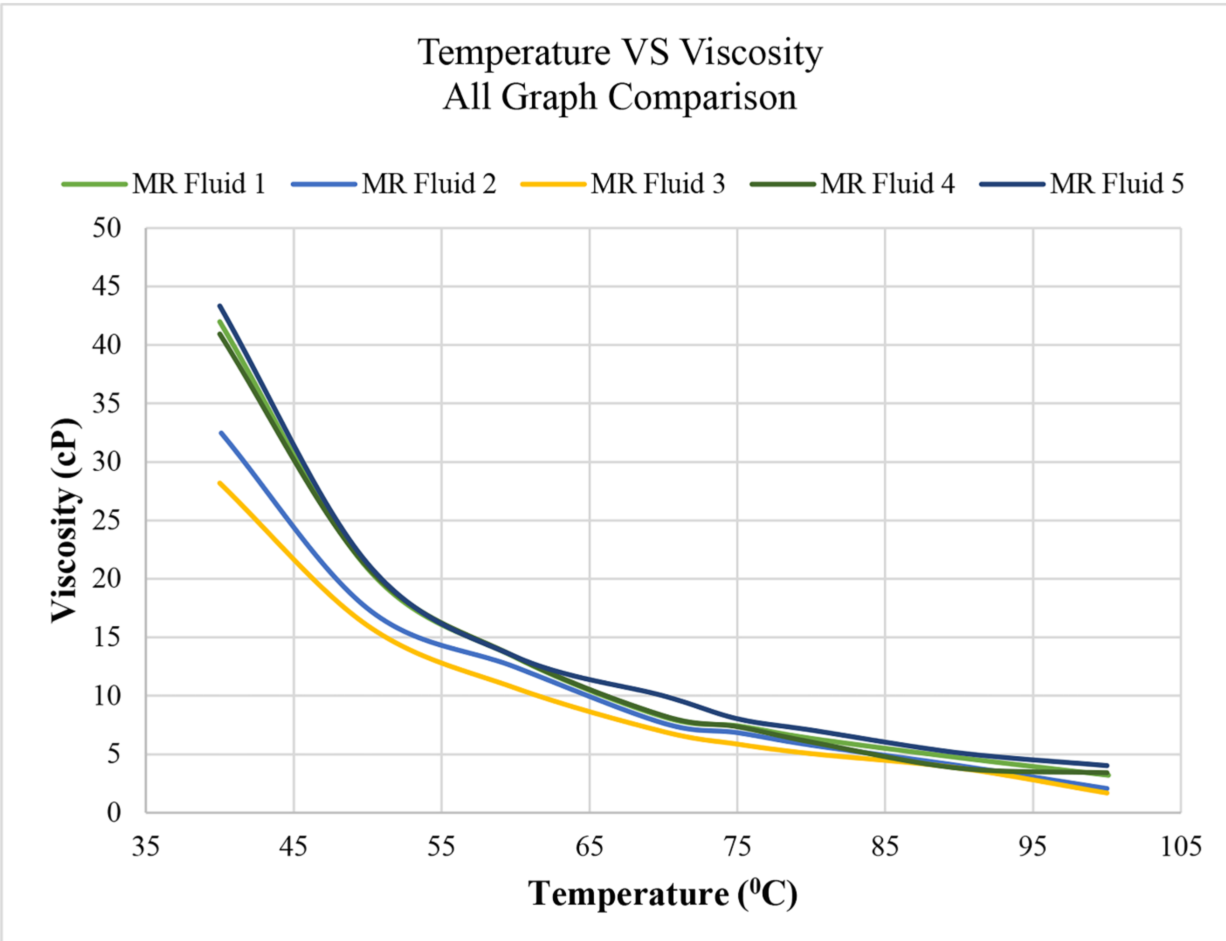


Fig.5.2.5 MR 5

CHAPTER 6

RESULT AND ANALYSIS

6.1 VISCOSITY VS TEMPERATURE



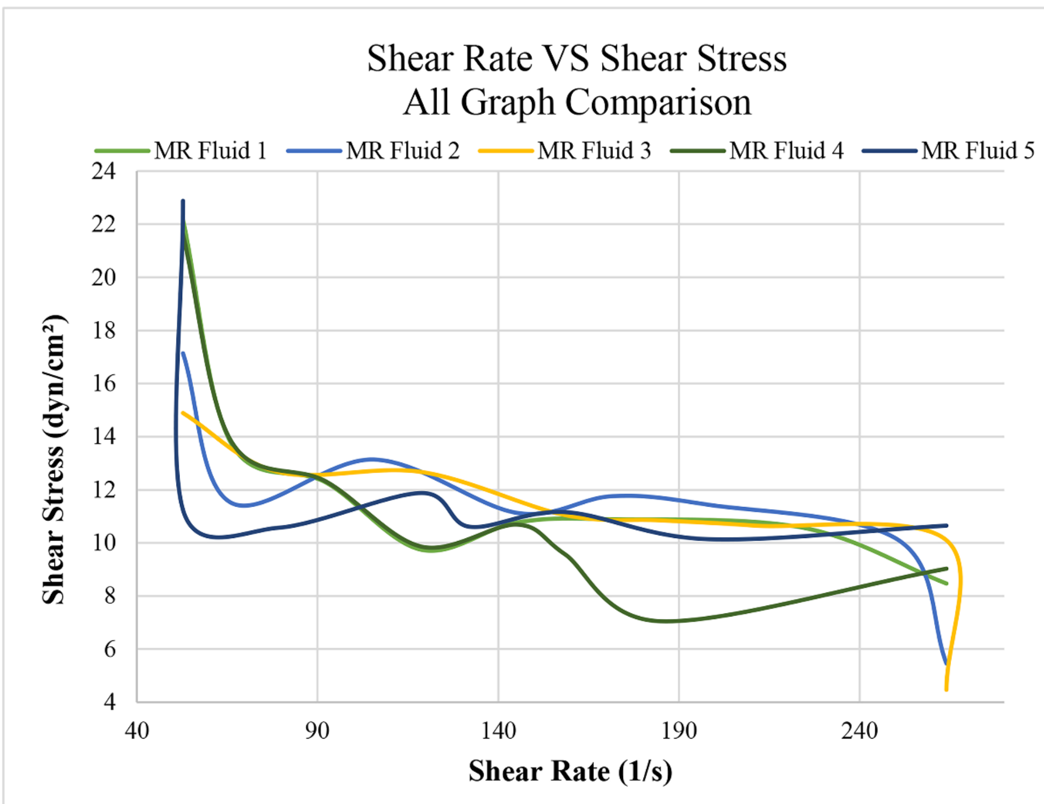
Graph 6.1.1

The influence of temperature on MR fluid is mainly shown as the influence on the viscosity, and the viscosity influences the shear stress. The temperature nearly does not influence the viscosity and shear stress of MR fluid under normal temperature (0~100°C) but influences the viscosity a lot under low temperature and high temperature because of carrier fluid and additive, and as a result, the mechanical property of MR fluid is influenced.

The mechanical property of MR fluid is highly influenced; the chaining of the material in the magnetic field is influenced, which causes the reduction of rheological properties, the uncontrollability of the shear stress, and even the failure of transmission.

MR 1, MR4 and MR 5 showed highest viscosity at low temperatures. The main reason behind this is because of the presence of Gum Arabic. The sudden drop in viscosity is between 45-55 degree Celsius, due the initial heating of silicone oil. The viscosity decreased as the temperature increases. The addition of any kind of additives does not improve the viscosity of the oil. The silicone oil viscosity decreased because of temperature affecting the entire MRF.

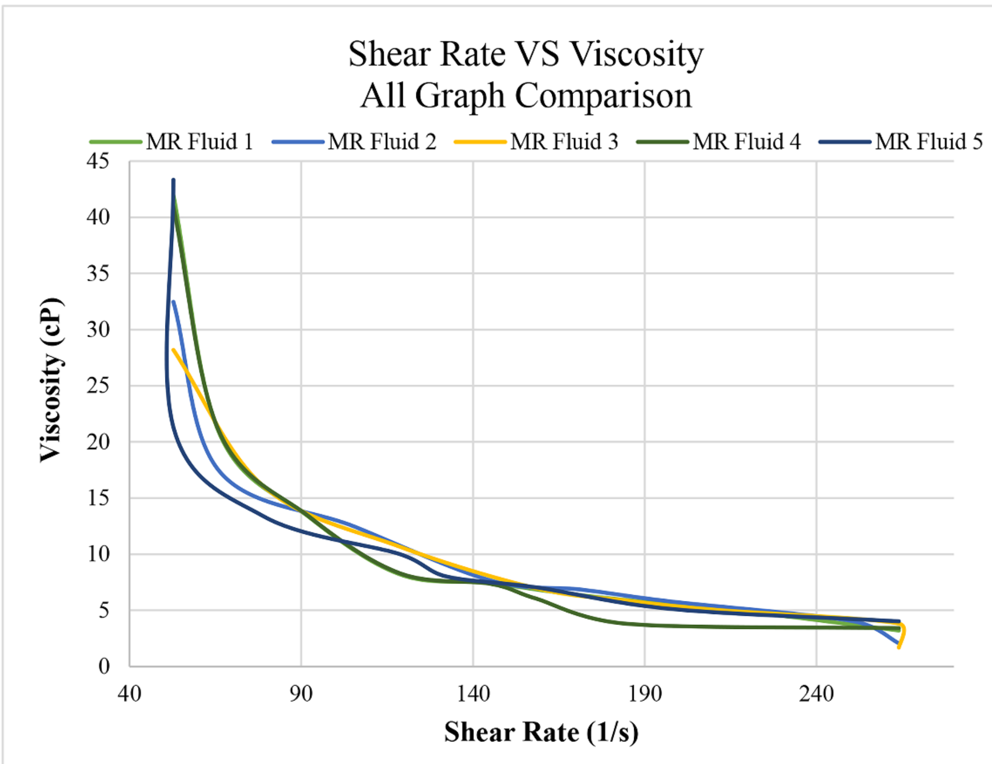
6.2 SHEAR STRESS VS SHEAR RATE



Graph 6.2.1

Fig represents the relationship between the shear rate vs shear stress. In this the results are taken in the absence of magnetic fields. The shear stress decreases slowly with higher shear rate, by comparing shear stress with shear rate, the MRF 1 shows higher shear stress than the MRF 2, MRF1 holds higher shear stress and is more stable, this enables the fluid more resistant to any form of movement with increasing shear rates. The shear stress resistance increases with increase in percentage of additive concentration.

6.3 SHEAR RATE VS VISCOSITY



Graph 6.3.1

Fig represents relationship between the shear rate and viscosity for MRF samples. The viscosity value is measured in cP, under zero magnetic field. In this experiment viscosity of the samples decreases with increase in shear rate. Here the sample having higher additive concentration shows higher viscosity value. The viscosity of samples is almost nearer at higher shear rate value.

Here, value of viscosity reduces with increasing value of shear rate. At low shear rate value, the viscosity of samples is higher under the higher magnetic field. At higher shear rate the viscosity value of the samples is same, i.e., they show Newtonian behaviour. At higher shear rate the value of viscosity is 3.21cP, 2.07cP, 1.69cP, 3.42cP and 4.03cP in samples of MRF1, MRF2, MRF3, MRF4 and MRF5 respectively.

6.4 SEDIMENTATION RATIO

The sedimentation ratio is obtained by visual change in the position of the boundary between the light and turbid portion of the carrier oil. The sedimentation Ratio can be defined as a ratio between the length of the clear and turbid portion of the MR fluid.

- Sedimentation ratio of MR 1=22%
- Sedimentation ratio of MR 2=30%
- Sedimentation ratio of MR 3=40%
- Sedimentation ratio of MR 4=25%
- Sedimentation ratio of MR 5=34.2%

The sedimentation is less in the samples having higher additive percentage. The sample MRF 3 shows stability against sedimentation having the best additive concentration, Improvement in the stability of the MR fluid is achieved by using small amount of additives. Thus, Gum Arabic and Citric Acid forms a good additive and surfactants for improving the stability.

CHAPTER 6

CONCLUSION

Silicone oil can be developed as a good alternative for mineral oil by considering the coefficient of friction, wear scar diameter, viscosity index. By adding suitable additives these properties were further improved when compared to mineral oil.

Tribological tests performed using Brookfield viscometer showed the viscosity variation of MRF with respect to temperature. The optimum concentration of the additive used such as gum Arabic improved the sedimentation stability.

In this study, the sedimentation ratio is much improved with the increase in concentration of additives such as Gum Arabic. The carrier oil viscosity also plays major part in sedimentation as the higher viscosity oil shows better sedimentation stability. In this study it is also observed that the shear stress resistance increases with increase in percentage of additive concentration. The sample having higher additive concentration shows higher viscosity value comparatively with other samples under same magnetic field intensity, the viscosity of both samples is almost nearer at higher shear rate value.

The results obtained can be summarized as follows; -

- The sample MRF 3 shows stability against sedimentation having the best additive concentration, Improvement in the stability of the MR fluid is achieved by using small amount of additives.
- At low shear rate value, the viscosity of samples is higher under the higher magnetic field. At higher shear rate the viscosity value of the samples is same, i.e., they show Newtonian behaviour.
- The viscosity decreased as the temperature increases. The addition of any kind of additives does not improve the viscosity of the oil. The silicone oil viscosity decreased because of temperature affecting the entire MRF.

CHAPTER 7

FUTURE ENHANCEMENT

Desired material properties could be either induced into the existing ordinary material or the existing properties of the material could be dramatically altered, giving rise to a class of materials called smart materials called MRF fluids. These new material properties can then be skilfully manipulated to tackle engineering problems. Each material possesses a property which can be altered, such as conductivity, viscosity and specific heat. The property altered determines the potential application of the resulting smart fluids.

The life of MRF is improved which forms the base of future machines. Thus, MR fluids is the future fluids in flow devices and semi actuators.

CHAPTER 8

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