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MAGNETORHEOLOGICAL FLUIDS: SYNTHESIS, CHARACTERIZATION AND ASSESSMENT OF THEIRRHEOLOGICAL BEHAVIOUR

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Abstract

Magnetorheological (MR) fluid is a type of smart material that exhibits fast, tuneable, and reversible changes in its rheological properties under the influence of a magnetic field. It is a suspension of small iron particles that can be arranged into chains when exposed to a magnetic field, resulting in a dramatic increase in the fluid's viscosity. A recent study investigated the properties of the three main components of MR fluid, namely soft magnetic particles, carrier fluid, and stabilizing agent, at high-temperature and developed a novel MR fluid that is resistant to sedimentation and temperature. The new fluid exhibited excellent sedimentation stability, higher shear yield stress, and less sensitivity to high-temperature environments, expanding its potential applications in MR devices.

Keywords: - magnetorheological fluid, magnetic field, viscosity, stabilizing agent, sedimentation

1. INTRODUCTION

MR fluids have been extensively researched for their potential applications in various fields, including aerospace, automotive, civil engineering, and robotics. They are used in dampers, shock absorbers, clutches, brakes, and other devices that require precise and rapid adjustments in their rheological properties.

The properties of MR fluids can be controlled by various factors, such as magnetic field strength, particle concentration, particle size, and temperature. The magnetic field strength determines the degree of alignment of the magnetic particles, which affects the fluid's viscosity. Particle concentration and size affect the stability and yield stress of the fluid. Temperature can affect the stability and rheological properties of the fluid, as well as the magnetic properties of the particles.

Recent studies have focused on developing novel MR fluids with enhanced properties, such as higher yield stress, faster response time, and improved stability. For example, researchers have explored the use of different types of magnetic particles, such as ferromagnetic, ferrimagnetic, and superparamagnetic particles, to improve the fluid's magnetic properties. Other studies have investigated the use of surfactants and stabilizing agents to prevent sedimentation and enhance the stability of the fluid.

Overall, the unique properties of MR fluids make them a promising material for various applications. Ongoing research and development are expected to further expand their potential uses and improve their performance.

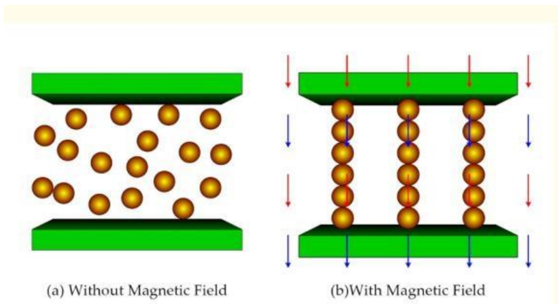

Figure 1: MR Fluid behaviour with and without magnetic field

2. SUSPENSION SYSTEM

The suspension system of an automobile is in charge of ensuring a comfortable and smooth ride by absorbing shocks and impacts from the road. There are several different parts that make it up, such as springs, shock absorbers, ball joints, and knuckle arms. The running gear, which consists of the tires, wheels, and brakes, is connected to the car body by the suspension.

Independent suspension, rigid leaf spring suspension, multi-link suspension, rigid axle suspension, air suspension system, and Macpherson suspension are just a few of the several types of suspension systems that are available. The choice of suspension system depends on the body type and planned use of the vehicle. Each type has benefits and drawbacks.

For the comfort, control, and safety of the vehicle, the suspension system is essential. In addition to offering stability when cornering, braking, and accelerating, it can adjust to various road conditions. Due to their complexity and enhanced handling capabilities, several suspension systems, such as the multi-link and Macpherson suspensions, are frequently found in high-end vehicles. Nonetheless, because of their ability to support huge loads, heavy-duty trucks may have rigid axle suspension systems.

Types of Suspension:

Damper or shock absorber: Its purpose is to absorb road and bump shocks. By absorbing the kinetic energy that is passed from the wheel to the frame and transforming it into thermal energy, it accomplishes this. For this reason, oil is poured into the dampers to keep them cool while they are continuously absorbing road shocks. In order to keep you from bouncing around in the car, a damper balances out the vibration.

Coils or Springs: Coils also serve as shock absorbers and compress in accordance with vehicle load. Coils and dampers work best together to limit body roll, which keeps the vehicle from tipping over during a fast turn.

Ball Joint: A ball joint serves as a rotation axis to smooth out the process because there are numerous rotational forces at play when a car turns.

Knuckle Arm: The steering arm, commonly referred to as the knuckle arm, joins the suspension to the wheel. A knuckle arm, a crucial component of the suspension system, serves as the link between the suspension and the wheel.

Components of Suspension system:

Springs: These are the parts that help the car support its weight and cushion road shock. Coil springs, leaf springs, and torsion bars are common spring types utilized in suspension systems.

Dampers (shock absorbers): These parts function to control the springs' motion, reducing the amount of bouncing the car experiences when it hits a bump or pothole. They also aid in enhancing the vehicle's stability when braking and turning.

Sway bars: These bars serve as a connection between the left and right suspension parts and assist in minimizing body roll when cornering.

Linkages: These are the bars and brackets that connect the rest of the suspension parts to the wheels and support them.

Tires and wheels: These parts serve as the vehicle's contact to the road and combine with the suspension system to offer a comfortable and smooth ride.

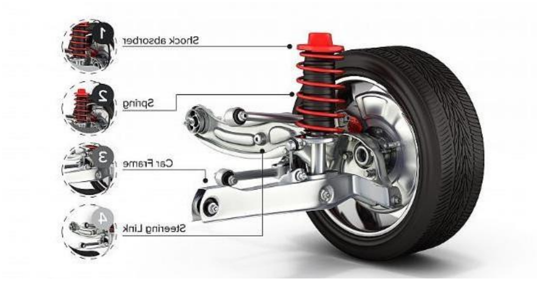

Figure 2: Various parts of the Suspension

3. QUARTER CAR MODEL

Figure 3: Quarter-Car Model

The sprung mass (vehicle) and upsprung mass are the two bodies that make up the two-body, quarter-car model. This model is frequently employed for researching the elements that influence the comfort and stability of moving objects. For both the tyre and the wheel as well as the spring and damper, the model incorporates stiffness and damping parameters. To determine the displacement of the car and increase comfort, the differential equations of the quarter car system can be solved. Numerical techniques can be utilized to represent the dynamic system of the quarter vehicle model in three different ways: signal-based, physical block diagram, and 3D multibody environment.

4. MR FLUID PREPARATION PROCESS

1) Guar gum and electrolytic iron particles were blended for 30 minutes at a 400-rpm stirring rate to create the combination.

2) Stearic acid and silicon oil were combined to create a solution, which was then agitated for 30 minutes at 400 rpm.

3) With constant stirring, the silicon oil solution was gradually incorporated into the electrolytic iron mixture.

4) To achieve a stable solution, the resultant MR fluid was constantly agitated for five hours.

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Prepared MR Fluid:

Four samples of different constituents have been prepared:

Sample	Constituents	Proportion (wt %)	Amount
1	Coconut oil	83.33	20ml
	E.I. Powder (Electrolytic iron)	16.67	4gm

Table 1: Composition of constituents used and their weight percentage of Sample 1

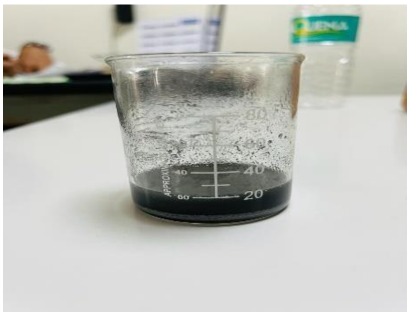

Figure 3: Test Sample 1

No additives were added in the first sample.
In the case of mineral oil, the rate at which viscosity changes in relation to temperature is higher. The use of mineral oils as a carrier fluid in MR fluid for low temperature applications is thus restricted as a result. Important characteristics of synthetic oil include its greater flash point, resistance to thickening at high temperatures, reduced friction, strong shear strength, and high viscosity index.

Sample	Constituents	Proportion (wt %)	Amount
2	Silicone Oil	75	15ml
	E.I. Powder (Electrolytic iron)	20	4gm
	Additive (Stearic acid + Guar gum)	5 (2.5 each)	1gm

Table 2: Composition of constituents used and their weight percentage of Sample 2

Figure 4: Test Sample 2

Only 5% additives were added in the second sample.
High flash points, very low vapour pressure, excellent temperature stability, and good heat transfer are all features of silicone oil. It is also resistant to oxidation. Yet, silicone oil is particularly challenging to seal. Physical characteristics don't alter much over a wide range of temperatures, and viscosity temperature slope is comparatively flat and serviceable from -40 to 204°C

Sample	Constituents	Proportion (wt %)	Amount
3	Silicone Oil	37	40ml
	E.I. Powder (Electrolytic iron)	60	51gm
	Additive (Stearic acid + Guar gum)	3 (1.5 each)	2.5gm

Table 3: Composition of constituents used and their weight percentage of Sample 3

Figure 5: Test Sample 3

The proportion of Electrolyte iron was increased in third sample to obtain more stable fluid and improve the density of fluid.

Sample	Constituents	Proportion (wt %)	Amount
4	Silicone Oil	32	20ml
	E.I. Powder (Electrolytic iron)	65	33.84 gm
	Additive (Stearic acid + Guar gum)	3 (1.5 each)	1.5 gm

Table 4: Composition of constituents used and their weight percentage of Sample 4

Figure 6: Test Sample 4

The proportion of Electrolyte iron was slightly increased and silicone oil was decreased in the fourth sample.

5. RESULTS

Property	Sample 1	Sample 2	Sample 3	Sample 4
Density (gm/cm^3)	0.68	0.90	1.66	1.88
Sedimentation rate (%)	66.67	66	14.7	23.52
Reaction Time (milli seconds)	18	17	14	11

Table 5: Density, Sedimentation rate and Reaction Time of samples

Sedimentation

The stability of MR fluids can be assessed by measuring their sedimentation rate (S.R.), which is the ratio of the volume of the supernatant liquid to the total volume of the mixture over a fixed period. The sedimentation ratio can be calculated using the following formula:

$$\text{S.R. (\%)} = \frac{\text{Volume of the supernatant liquid}}{\text{Volume of the entire mixture liquid}} \times 100\%.$$

The sedimentation ratio provides an indication of the stability of MR fluids. A high sedimentation ratio indicates that the particles in the mixture have settled to the bottom of the container, resulting in poor stability. In contrast, a low sedimentation ratio indicates that the particles are well-dispersed in the mixture and have not settled, indicating good stability. Therefore, monitoring the sedimentation ratio is an important aspect of evaluating the stability and performance of MR fluids in various applications.

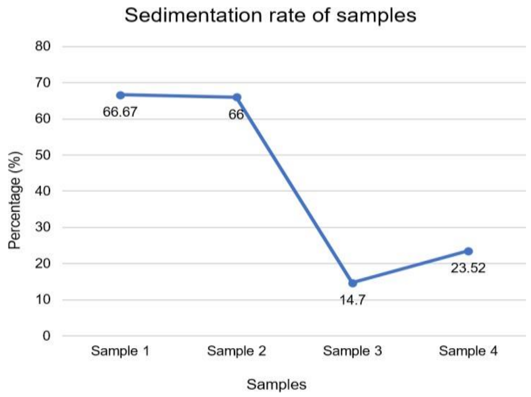

Fig. 7: Sedimentation rate of prepared samples

The first chart shows the density of each sample plotted against the sample number on the x-axis. We can see that Sample 4 had the highest density, followed by Sample 3, Sample 2, and Sample 1

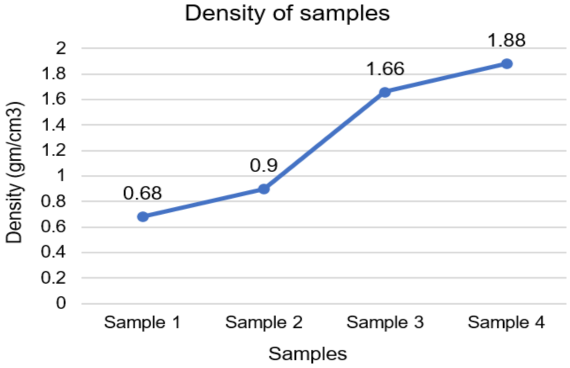

Fig. 8: Density of prepared samples

The second chart shows the sedimentation rate of each sample plotted against the sample number on the x-axis. This chart confirms the results shown in the table, with Sample 1 and Sample 2 having similar high sedimentation rates, and Sample 3 and Sample 4 having lower rates.

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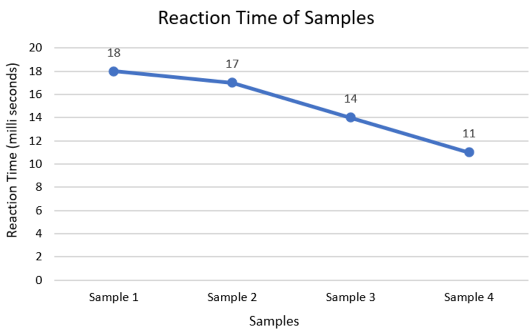

Fig. 9: Reaction time of prepared samples

The third chart shows the reaction time of each sample plotted against the sample number on the x-axis. This chart confirms the results shown in the table, with Sample 4 having the shortest reaction time of 11 milliseconds, while Sample 1 has the longest reaction time of 18 milliseconds.

Sample 4 has been selected for further testing to investigate its viscosity and other properties. With a density of 1.88 g/cm³, it is significantly denser than the other samples, which may indicate a higher concentration of certain components. The sedimentation rate of 23.52% also suggests that there may be some settling or separation of components within the sample. The shorter reaction time of 11 milliseconds indicates that the MR fluid sample responds more quickly to changes in magnetic field strength. These factors make Sample 4 an interesting candidate for more in-depth analysis.

To gain deeper insights into the properties of the MR fluid sample, we plan to measure its viscosity using a Zahn cup and an electromagnet. By applying a magnetic field around the Zahn cup, we can observe the fluid's behaviour and measure the time it takes to empty from the cup. This will help us understand how the magnetic field affects the fluid's flow properties and provide valuable information about its potential applications. With the use of an electromagnet, we can control the strength and orientation of the magnetic field to study the fluid's response under different conditions. These tests will allow us to gain a better understanding of the composition and properties of the MR fluid and how it can be used in various applications

Fig. 10: Electromagnet

An electromagnet and was constructed using a solid cylindrical iron core and copper wire. The wire was wound around the iron core over a length of 3.7cm, with a thickness of 1mm, and a total of 1090 turns. The purpose of the electromagnet was to produce a magnetic field that could be used to observe the behaviour of MR fluids

Fig 11: Electromagnet Test Setup for Magnetic Field Measurement using Gaussmeter.

The UGN3503 Hall Effect sensor is a magnetic field sensor that is capable of measuring the magnetic field strength at a given location. In this project, we are using this sensor to measure the magnetic field strength and display the result in Gauss.

The sensor is connected to the analog input pin A0 of the Arduino Uno board. A 10 kΩ resistor is also connected between the signal (out) pin of the sensor and the GND pin of the Arduino Uno board. The Vcc pin of the sensor is connected to the 5V pin of the Arduino Uno board and the GND pin of the sensor is connected to the GND pin of the Arduino Uno board.

To make the readings more accurate, a zero level value is subtracted from the raw value. Then, the raw value is divided by the GAUSS_PER_STEP constant value to obtain the Gauss value.

The GAUSS_PER_STEP constant value is the conversion factor between the sensor output in volts and the magnetic field strength in Gauss. In this project, we are using a GAUSS_PER_STEP value of 1.30, which means that for every 1.3 millivolts output by the sensor, the magnetic field strength is 1 Gauss.

Once the Gauss value is calculated, it is displayed on the serial monitor. The loop function then waits for 2 seconds before taking the next reading. The result can be plotted on a graph to get the magnetic field strength in Gauss as a function of distance from the magnetic source.The prepared Gaussmeter is a simple yet effective device that can measure the strength of magnetic fields in its vicinity using the UGN3503 Hall Effect sensor and Arduino Uno board. The device can be used in various applications such as magnetometry, position sensing, and current sensing.

Voltage (V)	Current (A)	Magnetic Field Strength (Gauss)
0	0	0.00
2	0.1	13.85
4	0.2	44.61
6	0.3	71.53
8	0.4	118.46
10	0.5	156.15
12	0.6	186.16

Table 6: Electromagnet Test Results

To determine the magnetic field strength produced by the electromagnet, voltage and current measurements were taken at different voltage levels. The voltage was varied from 0V to 12V, and the corresponding current and magnetic field strength were recorded. The results show that the magnetic field strength increased with an increase in voltage and current. At 12V and 0.6A, the magnetic field strength produced by the electromagnet was 186.16 Gauss.

The data obtained from these experiments can be used to determine the appropriate operating parameters for the electromagnet and provide valuable information for further experiments. This information can help to optimize the behaviour of the MR fluids and improve their potential applications.

Viscosity measurement

To measure the viscosity of the MR fluid, we used a 3D printed Zahn cup with a 5mm hole at the bottom. The Zahn cup has the shape of a test tube, and we filled it with 40ml of the prepared MR fluid. We placed the electromagnet that we had prepared earlier close to the Zahn cup, touching it. We varied the magnetic field strength by changing the voltage supplied to the electromagnet.

To measure the viscosity, we timed how long it took for the 40ml of MR fluid to empty out of the Zahn cup. We repeated the same process with 40ml of water as a reference fluid. We recorded the time taken for both fluids in seconds.

Using the recorded time, we calculated the viscosity of the MR Fluid using the formula:

$$\frac{\mathrm{DMR} \times \mathrm{t1}}{\mathrm{DW} \times \mathrm{t2}} \times \mathrm{y}$$

1) Density of MR fluid = DMR
2) Density of water = DW
3) Time taken for MR fluid to empty = t1
4) Time taken for water to empty = t2
5) Viscosity coefficient of water in centipoise = y

Then we divide the value in centipoise by 1000 to get the value of viscosity in Pa.S. Here, the density of the MR fluid was calculated before as shown in previous table by measuring the mass of a known volume of the MR fluid. Then we selected the density of water which is known to us.

The viscosity coefficient of water in centipoise was used as a reference value, as water is a well-known fluid with a known viscosity coefficient. We used the following values for water: density of water in gm/ml = 0.997, and viscosity coefficient of water in cp = 0.997. And for MR Fluid we used following value: density of MR Fluid in gm/ml = 0.997.

Using this method, we calculated the viscosity of the MR fluid at different magnetic field strengths, which are listed in the table below.

Voltage (V)	Current (A)	Magnetic Field Strength (Gauss)	Viscosity (Pa.S)
0	0	0.00	0.733
2	0.1	13.85	1.341
4	0.2	44.61	2.041
6	0.3	71.53	2.732
8	0.4	118.46	3.369
10	0.5	156.15	4.015
12	0.6	186.16	4.534

Table 7: Measurement of Viscosity, Current, Voltage, and Magnetic Field Strength

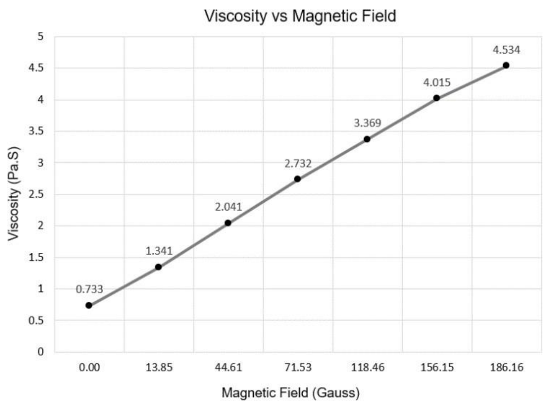

Fig. 12: Viscosity vs Magnetic Field

Based on the results of our testing, it appears that there is a direct relationship between magnetic field strength and the viscosity of the MR fluid. As the magnetic field strength around the fluid increases, so does its viscosity. This finding suggests that the MR fluid is responding to the magnetic field, potentially due to the presence of magnetic particles or ferromagnetic materials within the fluid.

This conclusion is supported by the line graph we have created, which clearly shows a positive correlation between magnetic field strength and viscosity. The graph shows a steady increase in viscosity as the magnetic field strength is increased from 0 to 138.29 Gauss. This trend is consistent with the behaviour of MR fluids, which are known to exhibit changes in viscosity in response to changes in magnetic field strength.

This information has important implications for the development of MR fluid-based devices and systems. By understanding the relationship between magnetic field strength and viscosity, researchers and engineers can design and optimize MR fluid-based systems to achieve the desired level of performance. For example, in a robotic system that uses MR fluid to control motion or damping, the optimal magnetic field strength can be identified to achieve the desired level of control.

In conclusion, our testing has demonstrated a clear relationship between magnetic field strength and viscosity in the MR fluid we tested. This finding has important implications for the design and optimization of MR fluid-based devices and systems, and highlights the potential of MR fluids in a wide range of applications.

6. REFERENCES

[1] J. S. Kumar et al, “A review of challenges and solutions in the preparation and use of magnetorheological fluids”, International Journal of Mechanical and Materials Engineering, (2019) 14:13.

[2] Suryawanshi Ravishankar, Rayappa Mahale, “A Study on Magneto Rheological Fluids and Their Applications”, International Research Journal of Engineering and Technology (IRJET), Volume: 02 Issue: 04, July 2015.

[3] N. P. Sherje and Dr. S. V. Deshmukh, “Preparation and Characterization of Magnetorheological Fluid for Damper in Automobile Suspension”, International Journal of Mechanical Engineering and Technology, 7(4), 2016, pp. 75–84

[4] A. V. Sonawane et al, “A Study of Properties, Preparation and Testing of Magneto-Rheological (MR) Fluid”, IJIRST –International Journal for Innovative Research in Science & Technology, Volume 2, Issue 09, February 2016.

[5] D. Cruze et al., “Study on Magnatec oil-based MR fluid and its damping efficiency using MR damper with various annular gap configurations’, Energy, Ecology and Environment, 31 May 2020.

[6] A. K. Bhalodi et al., “Magneto-Rheological Dampers in Automotive Suspensions”, International Research Journal of Engineering and Technology (IRJET), Volume: 03 Issue: 07, July-2016.

[7] S. K. Nimbalkar et al., “Development and Testing of MR fluid using Soybean oil as a carrier oil”, International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 04, Apr 2019.

[8] Mr. V. R. Sawalkar et al, “Preparation and Testing of Magneto Rheological Fluid”, International Journal of Technical Research and Applications, Volume 3, Issue 2, (Mar-Apr 2015), PP. 237-240.

[9] Y. Q. Guo et al, “Preparation and Experimental Study of Magnetorheological Fluids for Vibration Control”, International Journal of Acoustics and Vibration, Vol. 22, No. 2, 2017.