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Synthesis and Viscosity Analysis of Magneto-Rheological Fluid

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***Abstract*— The Magneto-rheological fluid is a smart fluid which changes its mechanical characteristics with varying magnetic fields. This principle of Magneto-rheological fluid is used in the human prosthesis, automotive shock absorbers, cockpit seats of military and commercial aviation etc. The purpose of this research is to synthesize an MR fluid using silicone oil as the constituent carrier fluid with other additives and to determine the coefficient of viscosity at varying magnetic field using Poiseuille's equation which is an indirect method of viscosity determination. The relationship curve between the viscosity of the synthesized fluid and the magnetic field over the varying range is plotted using the obtained results.**

Keywords*— *Magneto-rheological (MR) fluid; Viscosity; Synthesis.

I. INTRODUCTION

A Magneto-rheological (MR) fluid is a smart material, which responds to the varying magnetic field by changing its state. This fluid transforms from the liquid state to solid state under the application of the magnetic field and vice versa on the removal of the magnetic field [3]. This change in the state of the fluid with respect to the magnetic field is based on the phenomenon of the change in the viscosity of the fluid. The MR fluid constitutes micron sized particles over the range of 0.1 µm to 10 µm [7], which can be polarized magnetically, thus changing the rheological characteristics of the fluid. These micron sized particles are dispersed in the carrier fluid. Certain additives such as surfactants and anti-friction elements are used in addition to the carrier fluid. Surfactants are added in order to reduce the settling of the particles in the fluid, as the settling of these particles is unfavorable for the fluid [8]. The Anti-friction element reduces the friction between the particles in the MR fluid.

Under the application of the magnetic field, the micron sized particles get polarized and align themselves in the direction of the magnetic field, thus increasing the viscosity of the MR fluid. As the magnetic field is further increased, the viscosity of the fluid increases and accordingly increases the strength of the fluid. This leads to formation of a viscoelastic solid. The yield shear strength of the fluid enhances. The response time of the fluid to the magnetic field is in the order of milliseconds [2]. As the magnetic field is removed, the viscosity of the fluid decreases and attains its original state. Due to the applied magnetic field across the MR fluid, the shear stress versus shear rate can be controlled [4]. MR fluids can operate within a high temperature range, ranging from -65℃ to 200℃. High temperature facilitates the solidification of the MR fluid [1].

The objective of this paper is to synthesize an MR fluid and determine the viscosity of the synthesized MR fluid for the varying magnetic field by using the Poiseuille's equation, which is an indirect measurement method using a reference fluid with known properties. The properties of the synthesized MR fluid is determined at the certain values of magnetic field where the fluid flow stops, using the magneto burette setup [1].

II. EXPERIMENTAL DETAILS

The experiment was conducted by synthesizing the MR fluid with suitable carrier fluid, magnetic particles, surfactant and anti-friction element. The viscosity test of the synthesized MR fluid is carried out by using the magneto-burette setup.

A. Synthesis of MR Fluid-

The silicone oil is chosen as the carrier fluid with the composition of 66% weight by weight [2, 5]. The silicone oil has been chosen as the carrier fluid because of its high boiling point, good temperature stability, high flash point, oxidation resistance [5,6] and low melting point. The properties of the selected silicone oil is stated in Table I.

TABLE I. Properties of Carrier Fluid-
Silicone Oil

S.No.	Properties of Carrier Fluid – Silicone Oil	
1.	Physical state at 20 °C	Liquid
2.	Chemical Formula	$(Si(CH_3)^2O)_n$
3.	Colour	Clear colourless
4.	Odour	Odourless
5.	Flash point [°C]	113
6.	Boiling point [°C]	> 140
7.	Melting point [°C]	-40
8.	Density [g/cm^3]	1.061
9.	Vapour pressure mm/Hg	< 5 mm Hg at 25°C
10.	Viscosity at 20°C	0.370 – 0.390 Ns/m^2
11.	CAS Number	63148-62-9

The electrolytic iron particles are chosen as the magnetic particles with the composition of 20% weight by weight. Ball milling is used for the grinding of the electrolytic iron fillings

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in the MR Fluids. Size reduction of electrolytic iron fillings takes place from 56 microns to 10 microns. A ball mill is a type of grinder and it is used to grind and blend materials. The Ball milling process works on the principle of impact and attrition i.e. size reduction is done by impact as the balls drop from near the top of the shell. Toluene is used to undergo wet ball milling in order to avoid lumping or flattening of required material. The properties of the selected electrolytic particles is stated in Table II.

TABLE II. Properties of Magnetic Particles- Electrolytic Iron Filings

S.No.	Properties of Magnetic Particles – Electrolytic Iron Fillings	
1.	Physical state at 20 °C	Solid
2.	Chemical Formula	Fe
3.	Colour	Black
4.	Odour	Odourless
5.	Melting point [°C]	1535
6.	Boiling point [°C]	3000
7.	Density [g/cm^3]	7.86
8.	Solubility in water	Insoluble in water
9.	Particle Size in microns	0.1-10
10.	CAS Number	7439-89-6

The oleic acid is chosen as the surfactant with the composition of 10% weight by weight. The oleic acid is chosen as a surfactant because of its thermal and chemical stability. The properties of the selected silicone oil is stated in Table III.

TABLE III. Properties of Surfactant- Oleic Acid

S.No.	Properties of Surfactant - Oleic Acid	
1.	Physical state at 20 °C	Liquid
2.	Chemical Formula	$C_{18}H_{34}O_2$
3.	Colour	Pale yellow
4.	Odour	Peculiar Lard-Like
5.	Melting point [°C]	13 – 14
6.	Flash point [°C]	113
7.	Boiling point [°C]	194 – 195
8.	Vapour pressure	1 mm Hg at 176 °C
9.	Vapour density	9.7
10.	Density [g/cm^3]	0.89
11.	Solubility in water [% weight]	Insoluble in water
12.	CAS Number	112-80-1

The magnesium stearate is chosen as the anti-friction element with the composition of 4% weight by weight. The anti-friction element reduces the friction between the electrolytic iron particles in the MR Fluid. The properties of the selected silicone oil is stated in Table IV.

TABLE IV. Properties of Anti-Friction Element - Magnesium Stearate

S.No.	Properties of Anti-Friction Element - Magnesium Stearate	
1.	Physical state at 20 °C	Solid
2.	Chemical formula	$Mg(C_{18}H_{35}O_2)_2$
3.	Colour	White powder
4.	Odour	Odourless
5.	Melting point [°C]	200
6.	Density [g/cm^3]	1.028
7.	Solubility in water	Slightly soluble
8.	CAS Number	557-04-0

Each of the components are added with the continuous stirring time of 30 minutes. The resulting MR Fluid is prepared and is used for the viscosity testing.

B. Viscosity Test of the MR Fluid-

A test set-up is constructed for the viscosity testing of the MR fluid. This test set-up consists of- glass burette, burette stand, glass beaker, copper coil for coiling, ammeter, DC power source and stopwatch. The copper coil is used for coiling around the burette and the ends of coil is connected to the regulated DC power source. When the current is supplied to copper coil, a magnetic field is induced. The test set-up is shown in Fig.1.

The glycerin is taken as the reference fluid for the test, as its viscosity and density is known. The glycerin is added to the burette and time taken for 10 ml of glycerin to fall out of the burette is taken under presence and absence of magnetic field. The same is done for the synthesized MR Fluid and time taken for 10 ml fluid to flow out is noted.

Fig. 1.Magneto-burette test setup

C. Observations-

The experiment was conducted on MR fluid and glycerine (reference fluid) using the magneto-burette test setup. It was inferred that, with increase in the intensity of DC, the time taken for 10 ml of fluid to flow down increased. Thus, it was observed that fluidity of MR fluid decreases with the increase in the DC i.e. increased induced magnetic field.

The coefficient of viscosity of the MR fluid is determined. The following formula derived by Poiseulle's (1) will be used for this purpose [1]:

$$\eta = \frac{\rho.t.\eta_g}{\rho_g.t_g} \quad (1)$$

where:
ρ – density of the magneto-rheologic fluid (Kg/m^3)
t – outflow time of the magneto-rheologic fluid from the capillary (s)
ρ_g – density of the reference fluid (Kg/m^3)
t_g – outflow time of the reference fluid from the capillary (s)
η_g – viscosity coefficient of the reference fluid (Ns/m^2)

The relation between applied direct current and induced magnetic field assuming the setup as a solenoid is given by the following formula (2):

$$B= \mu.n.I \quad (2)$$

where:
B – Magnetic Induction (T)
µ - Magnetic Permeability of Free space = 1.25×10^{-6} Kg m s^{-2} A^{-2}
N – Number of Coils
I – Direct Current applied (Amps)

Observations were tabulated as shown in Table V.

TABLE V. Experimental Observation of MR Fluid

S.No.	Experimental Observation of MR Fluid			
	Current (A)	Magnetic Field (mT)	Viscosity of MR Fluid (Ns/m^2)	Time Flow of MR Fluid (s)
1.	0	0	1.062	179.98
2.	0.5	1.361	1.073	181.84
3.	1	2.723	1.095	185.56
4.	1.5	4.084	1.1328	191.97
5.	2	5.445	1.162	196.92
6.	2.5	6.807	1.203	204.02
7.	3	8.168	1.268	214.97

III. DISCUSSION OF RESULTS

From the obtained readings and corresponding calculations a graph was plotted between viscosity and the induced magnetic field. The resulting plot is shown in Fig.2.

It can be inferred from the graph that the change in viscosity with respect to the induced magnetic field increased stably until a point it clogged i.e. beyond the input of 3 ampere DC. At this point the fluid loses its fluidity.

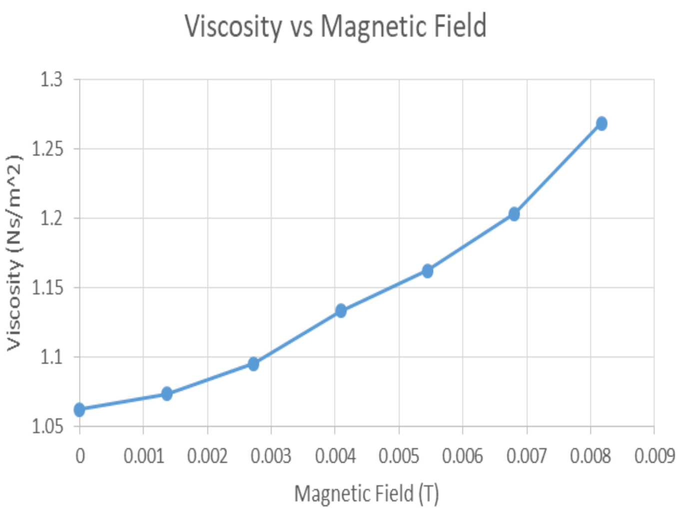

Fig. 2. Viscosity vs Magnetic Field plot for MR Fluid

IV. CONCLUSION

The synthesized fluid qualified the criteria of MR Fluid i.e. showing change in its viscosity with varying magnetic field. The taken composition of surfactant was sufficient to restrict the settling of iron particles and also the anti-friction element barred lump formation.

When subjected to magnetic field in the range of 0 mT to 9 mT, the fluidity decreased as expected and there after clogged. The composition of the synthesized MR fluid is suitable to be used within the above specified range.

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