Analytical determination of rheological parameters of MR fluids

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ABSTRACT

This paper aims to determine the stress of MR fluids in an on-state condition. Different MR fluids samples were made and tested inside the laboratory. The variation of the yield shear stress and viscosity with respect to magnetic field density for developed MR fluid samples is thus obtained using three above different techniques i.e. Carlson approach, relative permeability approach and experimental approach. The ratio of the conductivities of the MR fluid can be used to find the shear stress of the MR fluid when activated above high magnetic fields of the range of 2 tesla. It can be observed from these tables and figures that the results obtained from three approaches are matching quite well among each other and are having a percentage error range from 2% to 7%.

Keywords*: MR fluid, conductivity, relative permeability, Carlson approach*

1. INTRODUCTION

Magneto rheological fluid are used in now a days in various devices and equipments [1]. In the field of military operations where vibration mitigation is of utmost priority the MR fluids play a significant role [2]. The fluids can also be used in the landing gear of the aircraft where safety of the passengers is of utmost priority [3]. One needs to ascertain the shear stress of MR fluids to determine their on-state behavior [4]. In this research a novel technique of relative permeability is used to determine the yield stress of MR fluid. In this research the fluid is made and is characterized. The fluid is put between the poles of the electromagnet and is subjected to high torque [5]. The following equations are used to determine the yield stress of MR fluid.

$$B_{air\ gap} = \mu_o H \tag{1}$$

While magnetic flux density for on-state MR fluid is given as

$$B_{on} = \mu_o \mu_r H \tag{2}$$

where, μ_0 is permeability of air and is equal to $4\pi\times10^{-7}$ Henry/m. Using Eqs. (1) & (2), the relative permeability, μ_r, can be expressed mathematically as:

$$\mu_r = \frac{B_{on}}{B_{air\ gap}} \tag{3}$$

Equations (3) & (4) can be rewritten respectively for the particle loading (ϕ) of a fluid as:

$$\phi = \left[\frac{\tau_y}{C\times 271.7\times \tanh(6.33\times10^{-6}H)}\right]^{\frac{1}{1.5239}}$$

$$\phi = \left[\frac{B_{on} - u_0 H}{1.91 \times \left(1 - e^{-10.97 u_0 H}\right)} \right]^{\frac{1}{1.133}}$$

$$\left[\frac{\tau_y}{C \times 271.7 \times \tanh(6.33 \times 10^{-6} H)} \right]^{\frac{1}{1.5239}} = \left[\frac{B_{on} - u_0 H}{1.91 \times \left(1 - e^{-10.97 u_0 H}\right)} \right]^{\frac{1}{1.133}}$$

$$\left[\frac{\tau_y}{C \times 271.7 \times \tanh(6.33 \times 10^{-6} H)} \right] = \left[\frac{B_{on} - u_0 H}{1.91 \times \left(1 - e^{-10.97 u_0 H}\right)} \right]^{\frac{1.5239}{1.133}}$$

$$\text{or } \tau_y = 271.7 \times C \tanh(6.33 \times 10^{-6} H) \left[\frac{B_{on} - u_0 H}{1.91 \times \left(1 - e^{-10.97 u_0 H}\right)} \right]^{1.345} \quad (4)$$

Using Eq. (3.20) into Eq. (3.16), the resultant yield shear stress can be given as:

$$\tau_y = 271.7 \times C \tanh\left(6.33 \times 10^{-6} \frac{B_{on}}{12.56 \times \mu_r}\right) \left[\frac{B_{on}\left(1 - \frac{1}{\mu_r}\right)}{1.91\left(1 - e^{\frac{-10.97 B_{on}}{\mu_r}}\right)} \right]^{1.345} \quad kPa$$

2. Development of MR fluid

The MR fluid mainly consists of the following components

1. Carbonyl Iron particles are used to make fluid.
2. Silicon Oil is used to float the aforesaid particles.
3. Tetra methyl ammonium hydroxide is used to stop fluid from settling down under the effect of gravity.

3. Relative Permeability approach for fluid characterization

In order to characterize the MR fluid, one need an electromagnet equipped with a regulated power supply [6]. The current passes through the electromagnet and thereby energizes the fluid. One needs to measure the on-state conductivity of the fluid and off state conductivity of the fluid [7]. The ratio of the conductivities of the MR fluid can be used to find the shear stress of the MR fluid when activated above high magnetic fields of the range of 2 tesla [8]. However other approaches can also be used to characterize the fluid which are namely experimental and Carlson approach [9].

4. Results and Discussions

The variation of the yield shear stress and viscosity with respect to magnetic field density for developed MR fluid samples is thus obtained using three above different techniques *i.e.* Carlson approach, relative permeability approach and experimental approach. It can be observed from these tables and figures that the results obtained from three approaches are matching quite well among each other and are having a percentage error range from 2% to 7%.

Table 1 Viscosity and yield shear stress obtained from experimental approach for sample

Sr. No.	Current (A)	B_{on} Magnetic flux density (Tesla)	Torque (Nm)	On- state Yield shear stress (kPa)	On-state Viscosity (Pa-s)
1	0	0	0	0	0
2	0.2	0.183	0.114	6.175	73.433
3	0.4	0.249	0.166	8.949	106.410
4	0.6	0.312	0.219	11.800	140.317
5	0.8	0.398	0.294	15.882	188.852
6	1.0	0.453	0.342	18.456	219.453
7	1.2	0.521	0.395	21.310	253.396
8	1.4	0.587	0.436	23.475	279.139
9	1.6	0.645	0.460	24.814	295.057
10	1.8	0.706	0.478	25.749	306.173
11	2.0	0.753	0.486	26.213	311.699
12	2.2	0.803	0.492	26.528	315.441
13	2.4	0.855	0.496	26.735	317.903
14	2.6	0.909	0.498	26.861	319.403
15	2.8	0.955	0.500	26.927	320.183
16	3.0	0.992	0.500	26.962	320.598
17	3.2	1.033	0.501	26.988	320.910
18	3.4	1.076	0.501	27.006	321.125
19	3.6	1.108	0.501	27.015	321.234
20	3.8	1.151	0.501	27.024	321.335
21	4.0	1.182	0.502	27.028	321.385
22	4.2	1.212	0.502	27.031	321.421
23	4.4	1.24	0.502	27.033	321.446
24	4.6	1.29	0.502	27.036	321.476
25	4.8	1.313	0.502	27.036	321.486
26	5	1.34	0.502	27.037	321.494
27	5.2	1.363	0.502	27.038	321.500
28	5.4	1.381	0.502	27.038	321.504
29	5.6	1.403	0.502	27.038	321.507

Table 2 Viscosity and yield shear stress obtained from relative permeability approach for sample

Sr. No.	B_{on} Magnetic flux density (Tesla)	$B_{air\ gap}$ Magnetic flux density (Tesla)	Relative Permeability of MR fluid	On- state Yield shear Stress (kPa)	On-state Viscosity (Pa-s)
1	0	0	0	0	0

2	0.183	0.046	3.978	6.211	73.854
3	0.249	0.068	3.661	8.945	106.371
4	0.312	0.093	3.354	11.770	139.953
5	0.398	0.134	2.970	15.866	188.668
6	0.453	0.165	2.745	18.480	219.741
7	0.521	0.212	2.457	21.240	252.558
8	0.587	0.263	2.231	23.438	278.698
9	0.645	0.312	2.067	24.872	295.747
10	0.706	0.368	1.918	25.799	306.767
11	0.753	0.413	1.823	26.226	311.847
12	0.803	0.461	1.741	26.592	316.195
13	0.855	0.513	1.666	26.700	317.490
14	0.909	0.567	1.603	26.770	318.316
15	0.955	0.612	1.560	26.912	320.004
16	0.992	0.649	1.528	26.932	320.246
17	1.033	0.69	1.497	26.948	320.433
18	1.076	0.733	1.467	26.959	320.564
19	1.108	0.765	1.448	26.965	320.632
20	1.151	0.808	1.424	26.970	320.696
21	1.182	0.839	1.408	26.973	320.729
22	1.212	0.869	1.394	26.975	320.752
23	1.24	0.897	1.382	26.976	320.769
24	1.29	0.947	1.362	26.978	320.789
25	1.313	0.97	1.353	26.978	320.796
26	1.34	0.997	1.344	26.979	320.802
27	1.363	1.02	1.336	26.979	320.806
28	1.381	1.038	1.330	26.980	320.808
29	1.403	1.06	1.323	26.980	320.811

Table 3 Viscosity and yield shear stress obtained from carlson approach for sample

Sr.No	Magnetic field Intensity(Kamp/m)	B_{on} Magnetic flux density (Tesla)	$B_{air\ gap}$ Magnetic flux density (Tesla)	On- state Yield shear Stress (kPa)	On-state Viscosity (Pa-s)
1	0	0.000	0	0	0
2	25	0.131	0.031	4.243	50.460
3	50	0.233	0.062	8.283	98.494
4	75	0.315	0.094	11.952	142.122

5	100	0.382	0.125	15.145	180.089
6	125	0.439	0.157	17.822	211.920
7	150	0.488	0.188	19.997	237.784
8	175	0.532	0.219	21.720	258.268
9	200	0.572	0.251	23.057	274.165
10	225	0.610	0.282	24.078	286.310
11	250	0.646	0.314	24.849	295.476
12	275	0.681	0.345	25.426	302.332
13	300	0.714	0.376	25.854	307.424
14	325	0.747	0.408	26.170	311.187
15	350	0.780	0.439	26.403	313.958
16	375	0.812	0.471	26.575	315.993
17	400	0.844	0.502	26.700	317.483
18	425	0.876	0.533	26.792	318.574
19	450	0.908	0.565	26.859	319.371
20	475	0.939	0.596	26.908	319.953
21	500	0.971	0.628	26.943	320.378
22	525	1.002	0.659	26.969	320.688
23	550	1.034	0.690	26.988	320.914
24	575	1.065	0.722	27.002	321.079
25	600	1.097	0.753	27.012	321.199
26	625	1.128	0.785	27.020	321.287
27	650	1.159	0.816	27.025	321.351
28	675	1.191	0.847	27.029	321.397
29	700	1.222	0.879	27.032	321.431
30	725	1.254	0.910	27.034	321.456
31	750	1.285	0.942	27.035	321.474
32	775	1.316	0.973	27.037	321.487
33	800	1.348	1.004	27.037	321.496
34	825	1.379	1.036	27.038	321.503
35	850	1.411	1.067	27.038	321.509
36	875	1.442	1.099	27.039	321.512
37	900	1.473	1.130	27.039	321.515
38	925	1.505	1.161	27.039	321.517

39	950	1.536	1.193	27.039	321.518
40	975	1.568	1.224	27.039	321.519
41	1000	1.599	1.256	27.039	321.520
42	1025	1.630	1.287	27.039	321.521
43	1050	1.662	1.318	27.039	321.521
44	1075	1.693	1.350	27.039	321.521

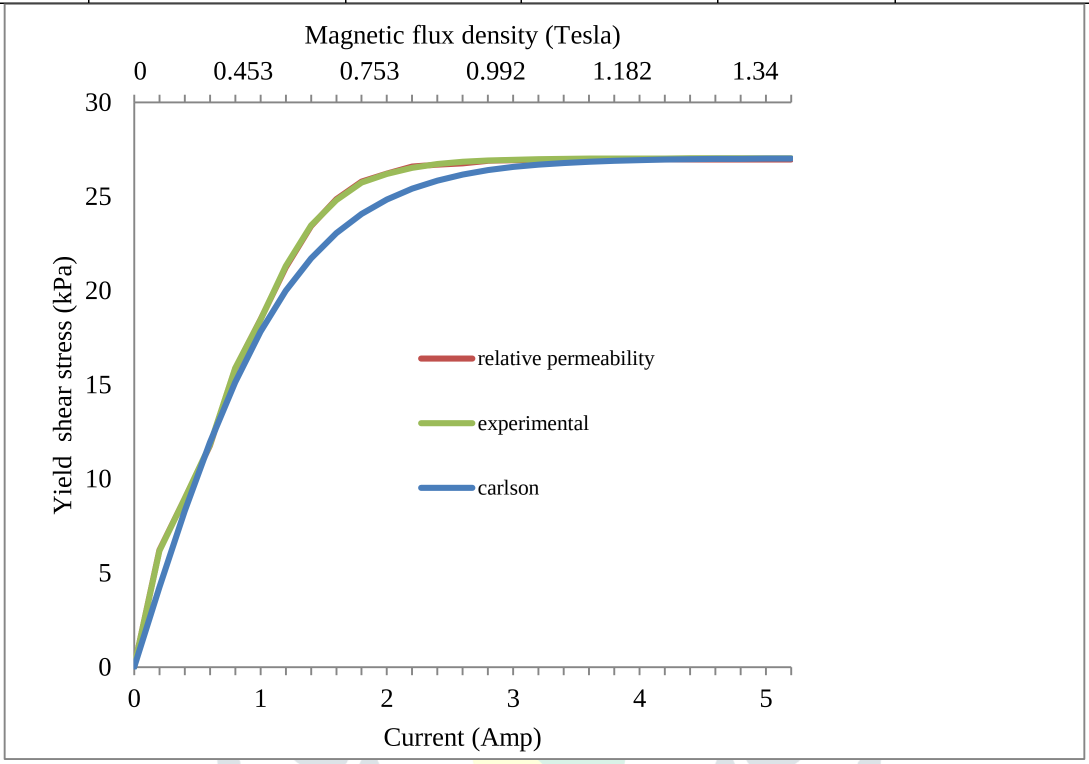

Fig. 1 Variation of yield shear stress with magnetic flux density for sample 1 by different approaches

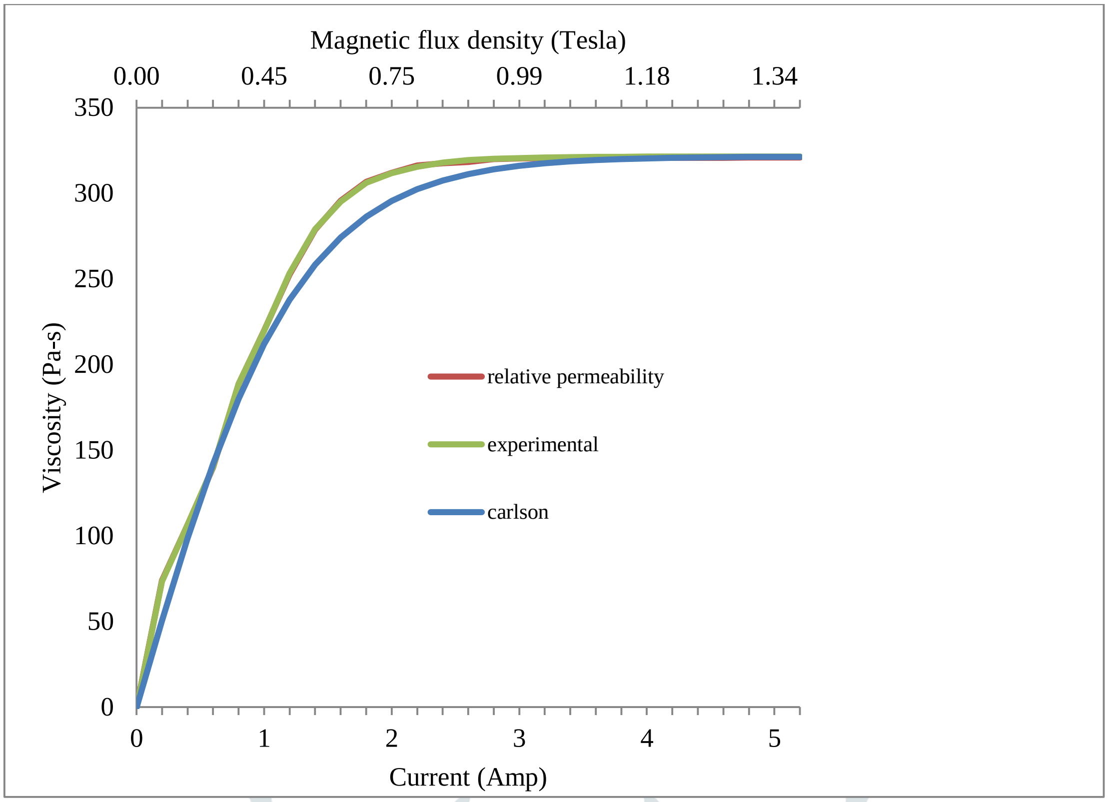

Fig. 2 Variation of viscosity with magnetic flux density for sample 1 by different approaches

5. CONCLUSIONS

This paper paves away for any researcher to develop MR fluids at very less cost. The variation of the yield shear stress and viscosity with respect to magnetic field density for developed MR fluid samples is thus obtained using three above different techniques i.e. Carlson approach, relative permeability approach and experimental approach. It can be observed from these tables and figures that the results obtained from three approaches are matching quite well among each other and are having a percentage error range from 2% to 7%.
It can be concluded that MR fluids yield stress can be found in an economical manner using a set up and can be used in various engineering ventures. This research can be used in determining the various parameters effecting fluid behavior

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