PREPARATION OF LOW-COST MRF AND ITS APPLICATION

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ABSTRACT

Magnetorheological fluid dramatically changes the mechanical, thermal, structural, and other rheological properties of the fluid. The attributed feature of this fluid is that it becomes solidified under the effect of an applied magnetic field. This is significantly due to the chain development of suspended molecules in the fluid medium. With the higher solubility of suspended iron particles, the Iron-Carbonyl-powder based MR fluid is the most widely used MR fluid. It has a magnificent scope in a variety of applications. Magnetorheological Fluid properties with different compositions of ingredients are synthesized to serve desired purposes.

This paper discusses the preparation of MRF by experimentation in order to reduce its market price. And hence make its application in a multi-purpose damper. MRF will be prepared contemplating leg prosthetics.

Keywords: Magneto-Rheological fluid, Viscoelastic solid, Cost reduction, MRF Damper, Prosthetics.

INTRODUCTION

History

A Fluid whose property may be changed by the applying of a magnetic/electric field is called a "Smart Fluid." Today, most of the smart fluids developed are those whose viscosity increases with a rise in the magnetic field. Properties of smart Fluids have been known for around sixty years, but were subjected to sporadic investigations up till the 1990s, and were mentioned into use in 2002 within the type of Magneto-Rheological Fluid.

Composition and functioning

The preparation of magneto-rheological fluids includes two components: solid phase and liquid phase. The solid phase consisting of magnetic particles is coated with additives like guar gum in a certain composition such that the volume to mass ratio of the particles increases. The liquid phase comprises the carrier fluid to which additives are added, in a particular manner and proportion, to increase the carrier fluid's density. The solid phase is then added to the liquid phase and mixed thoroughly for a certain period of time. The resulting mixture is then left undisturbed to observe the settling characteristics of the magnetic particles. The addition of stabilizers and additives often overcomes the problem of sedimentation.

The magneto-rheological fluid is like a homogeneous solution of the solid phase in a liquid phase where the solid phase particles behave as small magnets in the presence of a magnetic field and align along the magnetic field lines forming long chains. In the OFF state, the particles normally re disperses in the solution. The change in apparent viscosity of the magneto-rheological fluids in the presence of a magnetic field is the working principle of MR-based devices

Magneto-rheological fluid when subjected to a magnetic field, the fluid greatly increases its apparent viscosity, to the point of becoming a viscoelastic solid. Importantly, the yield stress of the fluid when in its active ("on") state can be controlled very accurately by varying the magnetic field intensity. The upshot is that the fluid's ability to transmit force can be controlled with an electromagnet, which gives rise to its many possible control-based applications. Extensive discussions of the physics and applications of MR fluids can be found in a recent book.

Problem Statement and Objectives

Given all the benefits, MRF is not so commonly used in its many multipurpose applications.The Magneto-rheological Fluid available in market is quite expensive; in the range of 10,000 to 34,000 to be precise. All the ingredients of MRF are not revealed in the research papers which make it challenging to prepare one.

Major objectives were to research and find major ingredients of Magneto rheological Fluid, to experiment and hence prepare MRF of unique composition to serve desired properties, and make use of thus prepared MRF in applications like prosthetics using MRF-damper.

.Abbreviations and Acronyms

MRF : Magneto Rheological Fluid

ERF : Electro Rheological Fluid

CI : Carbonyl Iron

PDMS : Polydimethylsiloxane

%wt. : Percentage by Weight

Units

Wb : Webers

cSt : Centistoke

µm : micrometer

Hrs. : Hours

Ingredients of MRF

MR fluid comprises of three main components:

a. Magnetic particles

b Carrier fluid

c. Additives.

Magnetic particles:- These particles mainly include ferrous compounds. They are used to react towards the magnetic power supplied. For example, iron carbonyl powder.

Carrier Fluid:- This type of fluid is used to bind together the magnetic particles and the additives. For example, Binding reagent.

Additives:- These are used to maintain the properties of the produced MR fluids. For example, guar gum powder

EXPERIMENTATION

Ingredient selection

With reference to research papers we came across ingredients tabulated in TABLE1, which were used most commonly in the magneto-rheological fluid so far.

The properties of each ingredient were studied and unnecessary ingredients were removed, to minimize preparation expenses. Selection was done on the grounds of properties that each ingredient show and the purpose they serve in MRF. The final ingredient list is as follows:

1. Iron Carbonyl Powder (5µm)
2. Silicone oil 225 cst
3. Guar-gum Powder (Thixotropic agent)
4. Additive x (Binding Agent)

Mechanical stirrer was used to stir MRF samples after adding calculated proportions of ingredients. Several trials were carried out each time composing ingredients in best possible manner to achieve required goals. After initial trials the desired effects of MRF was far from expected. After troubleshooting we realized that we lack a binding agent, which would bind together the iron carbonyl particles.

TABLE I. INGREDIENTS

Sr. No	***Common name***	***Chemical Name***	***Chemical formula***
1	Iron Carbonyl powder*	Carbonyl Iron	$[Fe(CO)_5]$
2	Silicone oil*	Polydimethylsiloxane	$(C_2H_{60}Si)_n$
3	Vegetable oil (Soybean)	Glycine max	$C_{11}H_9N_3O_2.Na$
4	Guar gum powder	Disodium	$C_{10}H_{14}N_5Na_2O_{12}P_3$
5	Lithium Stearate/Grease	Lithium octadecanoate	$C_{18}H_{35}LiO_2$
6	Graphite powder	Carbon	C
7	Oleic Acid	cis-9-octadecenoic acid	$C_{18}H_{34}O_2$
8	Iron oleate	Ferrous oleate	$C_{36}H_{66}FeO_4$

Making of MRF

Apparatus: 250ml Beaker*5, Gloves, Mechanical stirrer, Digital weighing machine (300g capacity), Guar gum Powder, silicone oil, Additive x, Earth magnets*4 of 5Wb capacity

TABLE II. EXPERIMENT SAMPLES

Sr. No.	***Ingredients used***	***Proportion %wt.***	***Duration of stirring***
Sample A			
1	Vegetable oil	60%	30 minutes
2	Iron Carbonyl Powder	37%	
3	Guar-gum Powder	0%	

Sr. No.	*Ingredients used*	*Proportion %wt.*	*Duration of stirring*
4	Additive x	3%	
Observations: (Refer to Fig 1.) 1. The Fluid showed viscoelastic nature. 2. Agglomeration was observed after sometime. 3. Vegetable oil oxidizes due to its poor resistance towards thermal oxidation			
Sample B			
1	Silicone oil	55%	
2	Iron Carbonyl Powder	40%	90
3	Guar-gum Powder	5%	minutes
4	Additive x	0%	
Observations: (Refer to Fig 2.) 1. Irregular intermixing of Iron carbonyl particles and silicone oil 2. High sedimentation ratio. 3. Guar gum powder and Silicone oil mixed well.			
Sample C			
1	Silicone oil	49%	
2	Iron Carbonyl Powder	46%	90
3	Guar-gum Powder	4%	minutes
4	Additive x	1%	
Observations: (Refer to Fig 3.) 1. Mild viscoelastic nature is observed. 2. Inappropriate response towards magnetic field. 3. Comparatively lower sedimentation ratio.			
Sample D			
1	Silicone oil	38%	
2	Iron Carbonyl Powder	55%	120
3	Guar-gum Powder	3%	minutes
4	Additive x	4%	
Observations: (Refer to Fig 4.) 1. Comparatively better viscoelastic nature is observed under magnetic field. 2. Additive x bound together the Iron Carbonyl particles. 3. Comparatively lower sedimentation ratio.			
Sample E			
1	Silicone oil	20%	
2	Iron Carbonyl Powder	72%	120
3	Guar-gum Powder	3%	minutes
4	Additive x	5%	

Sr. No.	*Ingredients used*	*Proportion %wt.*	*Duration of stirring*

Observations: (Refer to Fig 5.)

1. Rubber like viscoelastic nature is observed.
2. Considerable reduction in sedimentation ratio.
3. Regular mix is observed.

Fig.3. Sample C

Fig.4. Sample D

Fig.5. Sample E (1)

Before application of magnetic-field

Fig.6. Sample E (2)

After application of magnetic-field

The proportions of major ingredients were approximated to the research data collected. On the other hand the proportions of additives were finalized by trial and error. Inferences

Experiments were carried out to check effect of MRF ingredients on sedimentation ratio, and to observe properties it exhibits with different composition.

Sedimentation of all five samples was observed for 3 days in static condition visually after addition of each ingredient to judge its effect. Some ingredients put direct impact on physical behavior of MRF.

Liquid carrier, magnetic-particle ratio, presence of additive plays crucial role in making of MRF. Stability of the fluid depends substantially on the proportion of additives added.

Carrier Fluids

When carrier fluid is replaced from vegetable oil to silicone oil, change in physical properties was observed. The effect of carrier fluid on the stability of MRF was studied experimentally. In Fig. 7 it can be observed that both the carrier fluids do not have much difference in their sedimentation rate %.

Vegetable oil eroded with time due to poor resistance to thermal oxidation. Problem of erosion doesn't occur when silicone oil is used, credits to its high resistance to thermal oxidation. Silicone oil based MRF are long lasting, hence it qualified to be the carrier fluid.

Additive

Addition of additives apart from carrier fluid and Carbonyl Iron improvises stability of samples B, C, D, E every later more stable than the previous. Guar gum powder was used as an additive. Refer to Fig. 8. It implies that with increase in additive proportions and binding agent Additive x, sedimentation ratio decreases considerably.

On the other hand response to magnetic field reduced with the increase in additive proportions. Finalizing additive content was one of the most crucial tasks.

Magnetic particle

It was observed that with the increase in Carbonyl Iron content, stability and response to magnetic field improvised proportionally as expected. Refer to Fig. 9.

TABLE III. VARIATION IN SEDIMENTATION RATE WITH CHANGE CARRIER FLUIDS

Carrier fluid	**Sedimentation rate (%)**							
Vegetable oil	0	15	18	29	36	40	44	51
Silicone oil	0	13	16	24	30	36	41	46
Time (Hrs.)	0	10	20	30	40	50	60	70

(Refer Fig. 7. For graphical representation)

TABLE IV. VARIATION IN SEDIMENTATIO RATE WITH CHANGE IN PROPORTION OF ADDITIVE

Additive (%)	**Sedimentation rate (%)**							
B:3%	0	25	40	56	65	-	-	-
C:5%	0	20	32	52	58	-	-	-
D:7%	0	14	20	32	35	43	51	55
E:8%	0	10	15	26	32	39	44	46
Time (Hrs.)	0	10	20	30	40	50	60	70

(Refer Fig. 8. For graphical representation)

TABLE V. VARIATION IN SEDIMENTATION RATE WITH CHANGE IN PROPORTIONS OF CARBONYL IRON

CI (%)	Sedimentation rate (%)							
40	0	32	53	62	66	-	-	-
46	0	20	35	49	62	-	-	-
55	0	10	20	31	33	42	47	52
72	0	9	15	24	30	36	41	46
Time (Hrs.)	0	10	20	30	40	50	60	70

(Refer Fig. 9. For graphical representation)

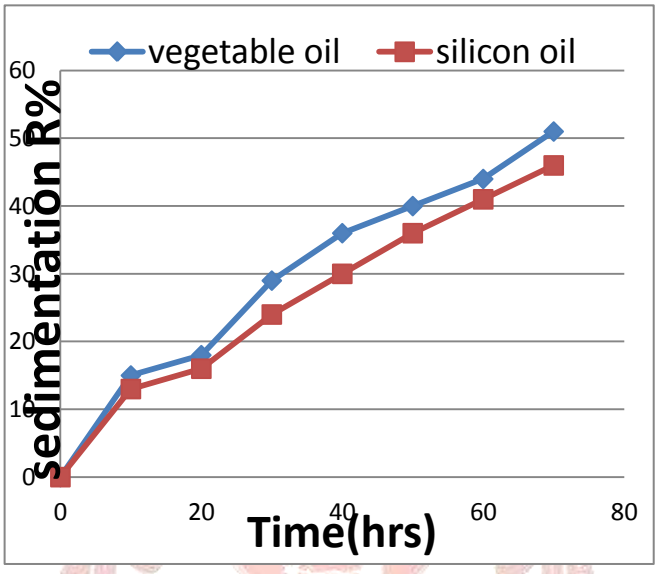

Fig. 7: Sedimentation Ratio vs Time, with carrier Fluids

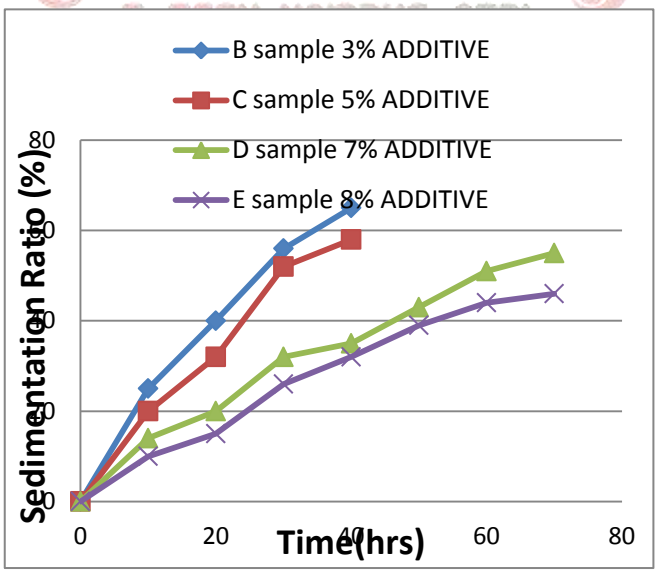

Fig. 8. Sedimentation Ratio vs Time, for Additive proportion

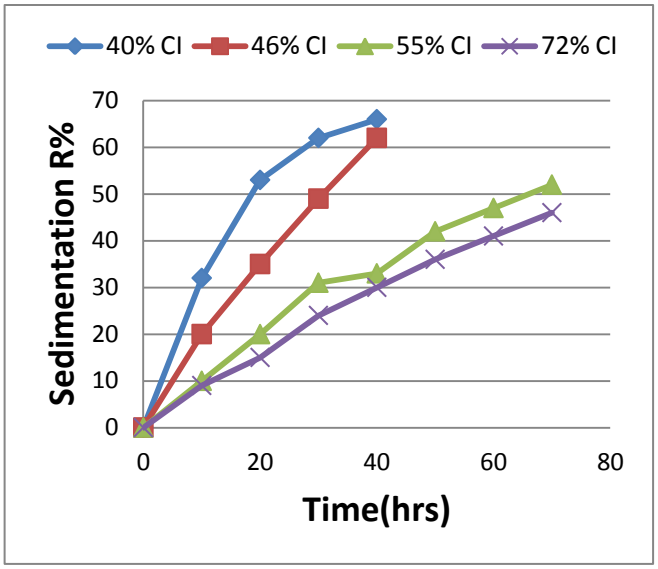

Fig. 9. Sedimentation Ratio vs Time, for Iron Carbonyl proportion

COSTING

Sr. No.	Ingredients	Proportion (% by wt.)	Mass (grams)	Price/ Kg (₹)	Price (₹)
1.	Iron Carbonyl Powder	72 %	720	3304	2378.88
2.	Silicone oil (225 cSt)	20 %	200	515	103
3.	Gaur gum powder	3 %	30	930	27.9
4.	Additive x	5 %	50	1000	50
Total		100%	1000 g	-	2559.78

Total cost of preparation of 1 Litre of MRF = **5836.2984 ₹**

CONCLUSION

- Magneto-rheological Fluid has been successfully prepared.
- MRF displayed all the desired physical properties before and after application of magnetic field.
- The preparation cost for 1 liter of MRF has been successfully reduced to 5836.2984 ₹ which is dramatically lower compared to the price of MRFs available in market.(10000₹ to 34000₹)

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