Journal of Physics: Conference Series

Magnetic effect in viscosity of magnetorheological fluids

To cite this article: H A Fonseca *et al* 2016 *J. Phys.: Conf. Ser.* **687** 012102

IMRMPT2015 IOP Publishing
Journal of Physics: Conference Series **687** (2016) 012102 doi:10.1088/1742-6596/687/1/012102

Magnetic effect in viscosity of magnetorheological fluids

H A Fonseca[1], **E Gonzalez**[1], **J Restrepo**[2], **C A Parra**[1] **and C Ortiz**[1]
[1] Universidad Pedagógica y Tecnológica de Colombia, Tunja, Boyacá, Colombia.
[2] Universidad de Antioquia, Medellín, Antioquia, Colombia.

E-mail: hugoalexander.fonseca@uptc.edu.co

Abstract. In this work the study of viscosity is presented for a magnetorheological fluid made from iron oxides micrometre, under an external magnetic field. The material was characterized by magnetic loops in a vibrating sample magnetometer and its crystal structure by X-ray diffraction. The results show that saturation magnetization and coercive field have dependence with the powder size. The material has different crystal structure which lattice parameters were determined by Rietveld refinement. The viscosity of the magnetorheological fluid was measured by a viscometer with rotational symmetry with and without external field. This result evidence a dependency on the size, percentage iron oxide and the applied magnetic field, it is due to the hydrodynamic volume of iron oxide interacts with the external magnetic field, increasing the flow resistance.

1. Introduction

The magnetorheological fluids are non-Newtonian fluids consisting of magnetic particles, example magnetite, dispersed in a liquid carrier that can change its rheological properties under application of an external magnetic field. Moreover, these fluids are characterized by an apparent viscosity, which decreases as spindle speed increase. Some of its applications are in suspension systems, magnetic separation industry and biomedicine [1-3].

In the preparation this class of fluids, particles of size micrometric or nanometre coated with a surfactant. It is necessary to generate a hydrodynamic volume that increase surface interaction between the magnetic particles and the carrier liquid and thus to reduce effects of aggregation and interaction in the presence of external magnetic field. These particles can be achieved chemically (cooprecipitation) or mechanical (milling) processes.

2. Experimental

Iron oxide powders were characterized by vibrating sample magnetometer to have an appreciation of behaviour magnetic and X-ray diffraction to quantify your composition and to know the crystalline structure. The magnetorheological fluid was prepared with micrometre-sized powders (T_5=15μm y T_2=40μm), oleic acid was used as surfactant, and the oxide/oleic acid ratio was kept at 1/1.5 in volume and SAE engine oil as carrier liquid, the samples are labelled T_2(15%), T_2(20%) and T_5(20%), the percentage value corresponds to the amount of oxide in the ferrofluid. The samples were heat treated (45°C up to 60°C in oleic acid and up to 50°C in engine oil SAE) in a mechanical shaker at cycles of 0.5, 1, 1.5, 2 hours to 43rpm. This process an activation chemical surface and suspension stability of magnetite in the liquid carrier is present due to the surfactant. The viscosity measurement was performed for various spindle speed without magnetic field and to different values of magnetic field with constant shearing rate at room temperature.

3. Result and discussion

In order to detect and quantify the phases, we refined the X-ray pattern of the sample by the Rietveld method. The experimental pattern as shown in Figure 1 was fitted using two phases, 89% magnetite, and 11% hematite, with cubic (Fd3m) and hexagonal (R3c) structures, respectively. With a refined adjustment of χ^2=1.905.

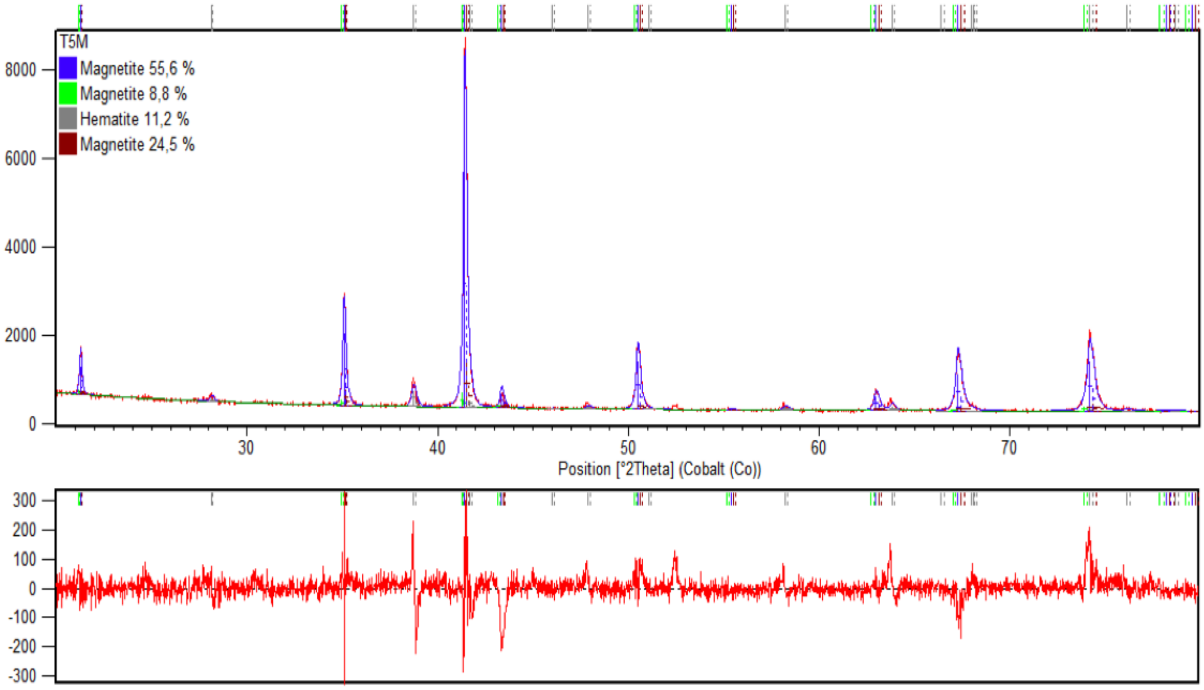

Figure 1. X-ray diffraction pattern and Rietveld fit of iron oxide sample.

In the Rietveld refinement it was necessary to introduce three cubic structures magnetite and a hematite hexagonal structure, which lattice parameters, are listed in Table 1.

Table 1. Refined lattice parameter of phases presents in the iron oxide: three of magnetite and one of hematite sample.

	Structural parameters		
Phase	a	b	c
Magnetite	8.3893(4)	8.3893(4)	8.3893(4)
	8.420(3)	8.420(3)	8.420(3)
	8.373(3)	8.373(3)	8.373(3)
Hematite	5.026(1)	5.026(1)	13.735(3)

The hysteresis loops show that the magnetic parameters such as saturation magnetization, coercive force and remanent magnetization are influenced by the magnetic domains state of the samples, which in turn it is a function of grain size [4,5]. That is, as it is increase the size of the oxide, saturation magnetization lowers (Figure 2) which values are within the range of a magnetically soft material as shown in Table 2, which is an important factor in the development of magnetorheological fluids. The magnetic behaviour of the oxide is due to the contribution of the crystal structures present in 89% magnetite and hematite 11%. Hematite presence generates slight changes in the magnetic properties of the sample compared to a pure magnetite [4,5].

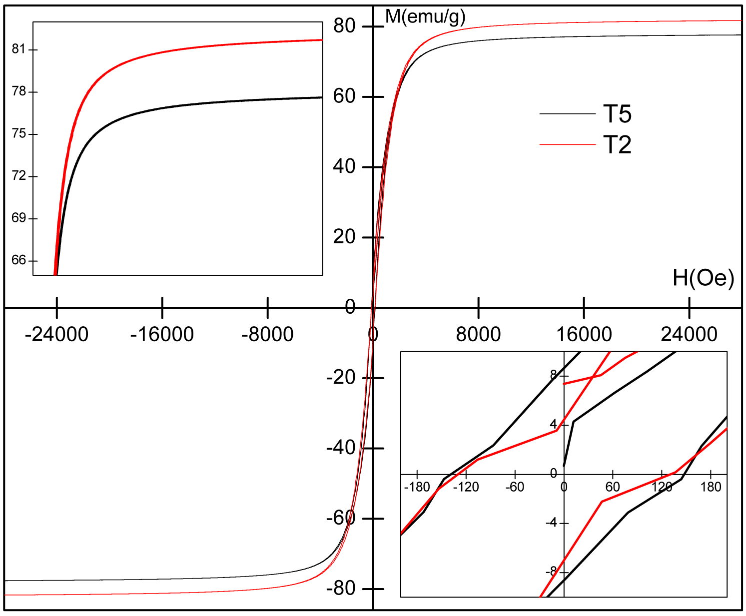

Figure 2. Iron oxide Hysteresis loops.

Table 2. Characteristic magnetic parameters: saturation magnetization Ms, remanent magnetization Mr, coercive field Hc.

	T_2	T_5
Ms (emu/g)	81.59	77.53
Mr (emu/g)	7.02	8.67
Hc (Oe)	132.2	144.62

The behaviour viscosity with spindle speed without applying field is shown in Figure 3(a). The viscosity versus spindle speed evidences a non-Newtonian behaviour. The values increase when the size of the oxide decreases, indicating better stability of oxide-oleic acid-oil [6,7]. The hydrodynamic volume is uniform and stable with the oxide size decrease, increasing flow resistance [8].

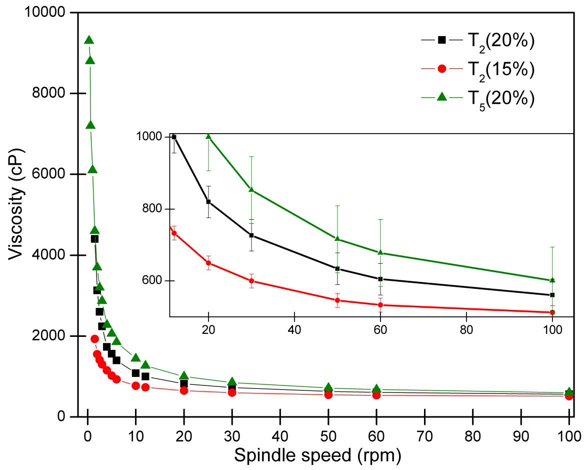

Figure 3(a). Viscosity behaviour varying the spindle speed with absence of magnetic field.

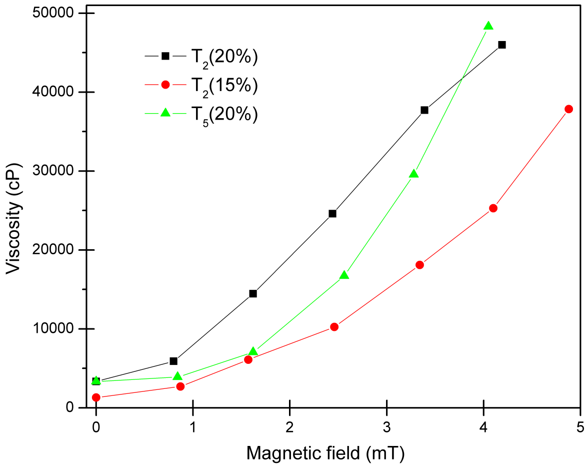

Figure 3(b). Viscosity behaviour varying the magnetic field with spindle speed to 2rpm.

In the Figure 3(b) show the viscosity in function of field applied for the spindle speed in this case was 2rpm. The change appears in several orders of magnitude in viscosity, due to micrometre oxide tends to align the applied field, increasing the torque in the spindle which registers the viscosity of the magnetorheological fluid [8] and it is caused by the formation of a robust chain structure.

The behaviour observed in Figure 3(a) can be characterized by a Bingham model with a yield stress, meaning that the suspensions acts as a solid-liked material when exposed to an external shear stress [9,10]. Regarding the oxide volume concentration, the viscosity increases due to the increases the hydrodynamic volume net giving the material a better response to the magnetic field. In the case of size of oxide, the viscosity does not depend on size in the presence of a magnetic field because the powder rotates seeking their preferred orientation. Magnetite, which contributes more in the magnetization, is the one that gives the orientation of the oxide in the fluid due to the external field.

4. Conclusions

The magnetorheological fluids prepared have a dependency on spindle speed acting as a plastic fluid conforms to the model Bingham. A clear dependence of the magnetorheological fluid with the magnetic field applied it was found that, because the micrometre oxide easily responds generating a preferred orientation to the applied field, thus increasing the resistance to fluid flow. Oleic acid surfactant satisfactorily fulfils the function of preventing the aggregation of magnetite due to magnetic interactions, thus behaving as a paramagnetic fluid. The crystal structures give an unusual magnetic response of the sample although their values are within those reported in the literature for a pure magnetite.

Acknowledgments

The authors thank the Centro de Gestión de Investigación y Extensión (CEDEC) of the Faculty of Engineering, call 001 for research groups.

References

[1] Scherer C and Figueiredo Neto A M 2005 *Brazilian J Phys* **35-3a** 718
[2] Yavuz C T, Arjun Prakash, Mayo J T and Colvin V L 2009 *J Chem Eng Sci* **64** 2510
[3] Shokrollahi H 2013 *Mater Sci Eng* C**33** 4485
[4] Christopher P Hunt, Bruce M Moskowitz and Subir K Banerjee 1995 *Magnetic properties of rocks and minerals in rock physics & phase relations: A handbook of physical constants* (Washington: Wiley & Sons)
[5] Özden Özdemir, Dunlop D J and Moskowitz B M 2002 *Earth Planet Sci Lett* **194** 343
[6] Guardia P, et al 2007 *J Mag Magn Mater* **316** e756
[7] López López M T, de Vicente J, González Caballero F and Durán J D G 2005 *Colloids Surf A Physicochem Eng Aspects* **264** 75
[8] Korobko E V, Novikova Z A and Zhurauski M A 2015 *J Phys Conf Ser* **602** 1
[9] Sedlacík M, et al 2010 *Smart Mater Struct* **19** 1
[10] Brookfield Engieering Labs 2014 *More solutions to sticky problems: A guide to getting more from your brookfield viscometer & rheometer* (http://www.viscometers.org/PDF/Downloads/More%20Solutions.pdf)