ELSEVIER

Journal of Magnetism and Magnetic Materials 252 (2002) 46–48

Journal of magnetism and magnetic materials

www.elsevier.com/locate/jmmm

Long-term stability of magnetic fluids in low-gradient magnetic fields

L.M. Pop[a,*], C.D. Buioca[b], V. Iusan[b], M. Zimnicaru[c]

[a] ZARM, University of Bremen, Am Fallturm, 28359 Bremen, Germany
[b] University of Petrosani, 20 University Street, 2675 Petrosani, Romania
[c] High School "Mihai Viteazul", 2692 Vulcan, Romania

Abstract

In order to study the long time behavior of different magnetic fluids placed in low-gradient magnetic fields, magnetization curves of magnetic fluids were determined using a measurement device based on Gouy's method and allowing the removal of clusters and aggregates. The time intervals of magnetic field exposure on the magnetic fluid samples were chosen between 10 min and 12 h. An important decrease of the magnetic fluids magnetization with increasing magnetic field intensity and exposure time has been observed. The analysis of the distribution function of particle size, for the initial and final samples, showed that the mentioned decrease is forced by large particle sedimentation in the magnetic field gradient and by gravitational sedimentation of clusters and aggregates formed by magnetic attraction of the small particles to the large ones. An "optimal" distribution function obtained for the final samples and ensuring a better long-term stability of the magnetic fluids in magnetic fields is suggested.

Keywords: Magnetic fluid; Stability; Equilibrium; Low-gradient magnetic field

1. Introduction

The behavior of different magnetic fluids in magnetic fields depends on the dimension of the particles contained in them, on the intensity and gradient of the magnetic field acting and on the time the fluids are exposed to the field. Cluster and aggregate formation, followed by sedimentation, is very difficult to be predicted theoretically, and therefore we have considered, from practical reasons, that the experimental study of the magnetic behavior of magnetic fluids, after different time interval of exposure to a magnetic field might be used as a tool to obtain the required information.

To set information about magnetic fluid structure changes during the measurement, we have used a special designed experimental setup based on the Gouy measurement method [1]. A glass tube, U shaped, containing the magnetic fluid was symmetrically placed with respect to the magnetic field created by the pole shoes of an electromagnet. A static pressure, measured with a manometric system, was applied to the magnetic fluid column in the tube, ensuring a constant length of the asymmetrical part of the magnetic fluid column and balancing the pressure caused by the magnetic force acting on this part (measured sample). The resulting magnetic force acting on the symmetrical part of the magnetic fluid column is always zero, due to the symmetry of the system, and does not influence the measurement results. In this way, large particles, clusters and aggregates sedimentation that occurs toward the symmetrical part of the magnetic fluid sample, does not affect the measurement results from the non-symmetrical part of the magnetic fluid sample, and therefore we can consider that clusters and aggregates which sediment are removed from the measured magnetic fluid sample. Using a manometric system we can measure the force that act on the non-symmetrical part of the magnetic fluid sample and determine its magnetization.

*Corresponding author.

0304-8853/02/$ - see front matter © 2002 Elsevier Science B.V. All rights reserved.
PII: S 0 3 0 4 - 8 8 5 3 (0 2) 0 0 6 9 0 - X

2. Theoretical aspects

The magnetization of a non-concentrated magnetic fluid is given by the Langevin type formula:

$$M_{\mathrm{MF}} = \varepsilon_{\mathrm{M}} M_{\mathrm{S}} \left[\sum_{i=1}^{N} \left(\coth \frac{\mu_0 V_{\mathrm{M}i} M_{\mathrm{S}} H}{kT} - \frac{kT}{\mu_0 V_{\mathrm{M}i} M_{\mathrm{S}} H} \right) p_i V_{\mathrm{M}i} \right] \frac{1}{\sum_{i=1}^{N} p_i V_{\mathrm{M}i}}, \quad (1)$$

where ε_{M} is the volume concentration of the magnetic phase, M_{S} is the saturation magnetization of the particles, p_i are the percentage of the particles having the magnetic volume $V_{\mathrm{M}i}$, H is the magnetic field intensity, k is the Boltzman constant, μ_0 is the vacuum magnetic permeability and T is the absolute temperature.

In order to obtain the distribution function of the particles by their magnetic diameters we have used Charles'method [2]. We have solved the N equation system with N unknown parameters (volume concentrations) and we have obtained the distribution function of the magnetic fluid particles for each analyzed sample.

3. Experimental results and discussion

Experimental results were obtained using stable magnetic fluids based on magnetite particles coated with oleic acid and dispersed in kerosene, having different values of the saturation magnetization. For each sample of magnetic fluid, the initial magnetization curve was determined in a short measurement time of 10 min. The magnetic fluid magnetizations for a given value of the magnetic field intensity (40, 80, 120, 320 kA/m) were determined after keeping the magnetic fluid in the magnetic field (the value of magnetic field gradient, ∇H, measured from the symmetry center of air gap between the pole shoes, on vertical direction, for the length of probe, increase from 0 to $12.69 \times 10^5\ \mathrm{A/m^2}$ on the first 5 cm and then decrease to $0.39 \times 10^5\ \mathrm{A/m^2}$ on the other 15 cm), during a time interval between 10 min and 12 h. The saturation magnetization was measured again 1 h after each set of measurement (time in which the magnetic field was zero), in order to verify the final loss of particles. The measurement error for magnetic field as well as for magnetization is in the order of 5%.

Analyzing the experimental magnetization curves obtained at different moments of time, we have observed that a decrease of magnetic fluid magnetization appears always.

Figs. 1 and 2 present the initial and final shape obtained after 12 h of magnetic field exposure of the distribution function of particle sizes, obtained for three typical magnetic fluid samples having saturation magnetization of 5.6 kA/m (sample 1), 10 kA/m (sample 2), and 11.6 kA/m (sample 3).

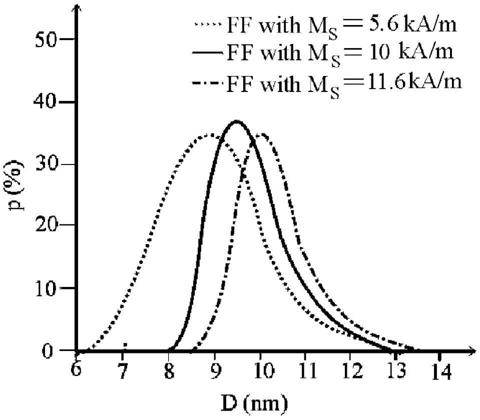

Fig. 1. Initial distribution functions of the particles by their magnetic diameter (p is the percentage of the particles having the magnetic diameter D).

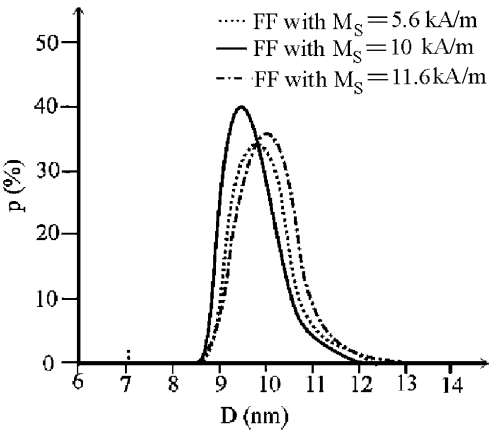

Fig. 2. Final distribution functions of the particles by their magnetic diameter (p is the percentage of the particles having the magnetic diameter D).

Three main important results were pointed out.

The first result is that a decrease of magnetic fluid magnetization with increasing magnetic field intensity as well as with increasing exposure time appears for all samples. A relative decrease of the saturation magnetization of the three samples, of about 30%, 20% and 10%, respectively, was finally obtained. A quasi-equilibrium of the magnetic fluids makeup is obtained after a time interval of 10 h.

The second result is related to the mechanisms leading to the decrease in magnetization. Large particles show strong interaction with the magnetic field and sediment in the vertical field gradient. On the other hand, very small particles are attracted by the large ones, form large clusters and aggregates which sediment in the gravitational and magnetic field. This was suggested by the analysis of the distribution functions for all samples. For sample 3, large particles (with diameters from 13 to 14 nm) were removed. Reversibility measurements have shown a final relative loss of saturation magnetization of 2%, which indicates that the rest of 8% is caused by cluster formation including small particles, which is reversible after magnetic field removal. A final relative loss of 10% and 20% has been obtained for samples 2 and 1, respectively, which indicates a higher amount of large clusters and aggregates formed and sedimented in these samples.

The third result is that the distribution functions of the particles by their magnetic diameters for the final obtained samples have a very close shape, ensuring a better stability of the final magnetic fluid samples with respect to the initial ones—having much different distribution functions. The wider the distribution function of particle sizes is, the less stable the magnetic fluid. This is in agreement with several studies suggesting that a narrow distribution function of the magnetic particle diameter leads to a better stability of the magnetic fluids in magnetic as well as gravitational fields [3].

4. Conclusions

The determination of magnetization of magnetic fluids after a long time interval of exposure to a low-gradient magnetic field, using a measurement device allowing large particle, cluster and aggregate removal from the measured sample, has shown an important decrease of saturation magnetization of the magnetic fluids. The larger is the distribution function of the particles by their magnetic diameter, the higher is the magnetic fluid magnetization decreasing.

For a given class of magnetic fluids (in the studied case—based on magnetite particles coated with oleic acid and dispersed in kerosene), the most stable samples are those with an "optimal" distribution function of the particle sizes, characterized by a lower loss of magnetization and a higher reversibility of cluster formation after magnetic field removal.

The long-term stability measurements can be also used as a method to process magnetic fluid samples in order to obtain more stable ones, for technical applications requiring the presence of magnetic fluids in low-gradient magnetic fields.

The analysis of the results obtained using this method leads us to the conclusion that ulterior investigations, using non-numerical methods, can be useful.

References

[1] C.D. Buioca, L. Pop, Ann. Univ. Petrosani, Phys. 1 (1999) 131.

[2] V. Iusan, C.D. Buioca, Rom. Rep. Phys. 47 (3–5) (1995) 281.

[3] D.V. Berkov, J. Magn. Magn. Mater. 104–107 (1992) 1540.