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Concentrated magnetic fluids on water and short chain length organic carriers

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Abstract

Magnetic fluids on methyl-ethyl-ketone, ethylic ether, i-propanol, i-butanol and water were prepared applying double layer of surfactants to ensure the colloidal stability of samples of saturation magnetization up to 50 kA/m. Magneto-optical, magnetic, rheological and magnetorheological measurements evidence the different behaviour of samples depending on the polarity of carriers, concentration and combination of surfactant bilayers.

Keywords: Magnetic fluids; Strongly polar carriers; Double-layer stabilization; Magnetic and flow properties; Light scattering

1. Introduction

Preparation and stability of dispersions of double-layer coated magnetic nanoparticles in various organic polar carriers, mainly alcohols, were discussed in Refs. [1–3]. The mechanism and efficiency of double-layer sterical stabilization of magnetic nanoparticles in aqueous medium were thoroughly discussed in Ref. [4].

In this letter we report on results concerning concentrated magnetic fluids on very short chain length, highly polar, organic carriers and on water.

2. Samples

Following the main steps of the preparation procedures described in Refs. [3,5], double-layer coated magnetite nanoparticles were dispersed in methyl-ethyl-ketone (MEK), ethylic ether (EE), i-propanol (i-Prop), and i-butanol (i-But) carriers, using chemically pure oleic acid (OA) as primary and technical grade dodecylbenzensulphonic acid (DBS) as secondary surfactant layer. For comparison, also n-pentanol (P)-based magnetic fluid [3] was prepared. The OA monolayer covered magnetite nanoparticles were extracted from the *same* petroleum-based, well purified, primary magnetic fluid, for *all* the organic polar samples mentioned above, in order to investigate the influence of the carrier liquid only.

The physical volume fraction of magnetite particles was set close to 0.12 in order to have a saturation magnetization of approximately 500 G (40 kA/m).

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Stable dispersions of magnetic nanoparticles in water (MF/W) were obtained using surfactants with different chain lengths, such as dodecyl-benzen-sulphonic acid (DBS), lauric acid (LA) and miristic acid (MA). The samples with DBS double-layer coated magnetite nanoparticles were obtained according to the method given in Refs. [6,3]. The most concentrated water-based sample of this type, with physical volume fraction of approximately 0.15, was kept after preparation in a well closed container a long period of time ($\approx$19 years). Visible sedimentation of large agglomerates was not observed. Lower magnetization samples were obtained by dilution with distilled water (free of surfactant). In the case of LA–LA bilayer, the preparation/stabilization procedure is somewhat different, due to the presumably different interpenetration lengths of DBS and LA molecules in double layers [4].

Besides the already mentioned DBS–DBS stabilized concentrated sample, water-based samples with DBS–DBS, LA–LA, LA–DBS and MA–DBS stabilizing bilayers were prepared, with saturation magnetization of approximately 100 G (8 kA/m).

3. Results and discussion

The magnetic induced phase separation was observed by means of optical microscopy. The condensed phase drops appear like opaque needles (10–20 μm long and 2–5 μm thick) aligned in the external magnetic field direction.

The static light scattering experiments were done by measuring the extinction of a 4 mW He–Ne laser beam in the magnetic fluid sample. By using an iris in order to filter out the scattered light, *the relative extinction* $\mathrm{Ext}(H) = [I(H=0) - I(H)]/I(H=0)$ of the light was measured, where $I(H=0)$ is the transmitted light intensity in the absence of the field and $I(H)$ the transmitted light in the presence of the field. Thus, $\mathrm{Ext}(H)$ can be used as a qualitative measure for the degree of the phase condensation in the magnetic fluid sample [7].

In Fig. 1 the time dependence of the relative extinction at 22 °C, for several values of the external field strength, is plotted for sample MF/W (49.8 kA/m saturation magnetization). After the field is turned on, the relative extinction increases and saturates and after the field is cancelled it suddenly drops to zero. The condensation process is stimulated by the increase in the external field strength and the kinetic process is slower at intermediate fields (28–80 kA/m). The condensation process is reversible, i.e. the sample returns to the initial monophasic state after the field removal.

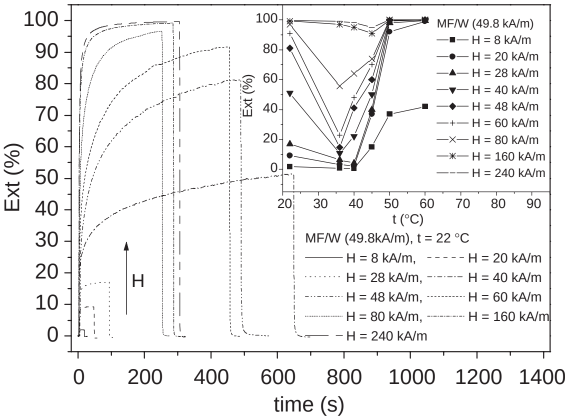

Fig. 1. Extinction data for sample MF/W (49.8 kA/m).

In the inset of Fig. 1 the temperature dependence of the saturation values of the relative extinction at several values of the external magnetic field is plotted. The condensation process is inhibited when the sample is heated up toward 35–45 °C and stimulated when the sample is heated up over 45 °C. The samples MEK and i-But were found to be stable regardless of the temperature and field strength. The condensation process in the sample i-Prop is very weak: the saturation value of the relative extinction at 22 °C and 40 kA/m was 0.5%, much smaller than 51%, measured in the case of the aqueous sample (Fig. 1, inset). In the case of sample EE the saturation value at 30 °C and 80 kA/m was 30%, about twice smaller than in the case of the aqueous sample.

Normalized magnetization curves were analysed mainly to study the cluster formation in the newly prepared water-based magnetic fluids since, on purpose, the small particle clusters were not visible in the light scattering measurements. The saturation magnetization M_s was obtained as in Ref. [8]. Assuming the same size distribution of particles in the studied samples (see the Sample section), the ratio M/M_s is influenced by the microstructural properties only [8]. The most sensitive part of the magnetization curves to cluster formation is the low field region.

Fig. 2 shows that the water-based samples containing particles coated with a double layer of DBS have a significant fraction of agglomerates. The size of the clusters increases with the volume fraction of particles, which leads to a higher initial slope of the curves in comparison to that of the pentanol-based sample. Since no condensed phase was observed for these samples in light scattering experiments up to approximately 800 A/m, we may conclude that the particle clusters in zero field, which very likely grow in the presence of the field, are dominant in these samples. On the contrary, when a different primary surfactant was used, the degree of aggregation decreased. The particles surfacted with MA–DBS appear to have similar microstructural properties as the pentanol-based sample, i.e. much less