

## MAGNETIC NANOFUIDS PROPERTIES AND SOME APPLICATIONS

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Synthesis, complex characterization methods and some applications of various types of magnetic nanofluids are presented. The structure and magnetic field induced particle aggregation processes at nanometric level of magnetic nanofluids on strongly polar carriers were analysed, using data obtained by magnetic, rheological and magnetorheological, as well as SANS measurements.

*Key words:* magnetic nanoparticles, magnetic nanofluids, chemical synthesis, nanostructure, magnetic properties, rheological properties, magnetorheological properties, neutron scattering, applications.

### 1. INTRODUCTION

Magnetic nanofluids (known also as ferrofluids or magnetic fluids) are a special category of smart nanomaterials, in particular magnetically controllable nanofluids [1]. These types of nanofluids are colloids of magnetic nanoparticles, such as  $\text{Fe}_3\text{O}_4$ ,  $\gamma\text{-Fe}_2\text{O}_3$ ,  $\text{CoFe}_2\text{O}_4$ , Co, Fe or Fe-C, stably dispersed in a carrier liquid [2]. Consequently, these nanomaterials manifest simultaneously *fluid* and *magnetic* properties. Macroscopically, the introduction of magnetic forces into the fundamental hydrodynamic equations for the quasihomogeneous magnetizable liquid medium gives rise to the magnetohydrodynamics of magnetic nanofluids, known also as *ferrohydrodynamics* and opens up an entire field of new phenomena [3] and promising applications [4]. From a microscopic point of view, long-range, attractive van der Waals and magnetic forces are ubiquitous and therefore must be balanced by Coulombic, steric or other interactions to control the colloidal stability of dispersed nanoparticle system, even in intense and strongly non-uniform magnetic field, specific to most of the applications [5,6].

Many of the envisaged applications, *e.g.*, rotating seals or bearings, require magnetic fluids with high magnetization and at the same time, with long-term colloidal stability. These requirements are difficult to fulfill simultaneously and

implies severe conditions on the stabilization procedures applied during the synthesis of magnetic nanofluids.

In what follows, the composition, structure and properties of various types of magnetic fluids are presented, referring also to technological and biomedical applications envisaged for these nanofluids.

## 2. CHEMICAL SYNTHESIS OF MAGNETIC NANOFLUIDS

The synthesis of magnetic fluids has two main steps: (a) the preparation of nano-sized magnetic particles and (b) the subsequent dispersion of the nanoparticles in various non-polar and polar carrier liquids. In what concerns the ferrite nanoparticles, the most efficient route is the chemical co-precipitation process [2]. The details of the multi-step procedures applied at the Laboratory of magnetic fluids from Timisoara are given in [7–10].

The *synthesis of surfactant covered magnetite nanoparticles* has the following steps: co-precipitation (at  $t \approx 80^\circ\text{C}$ ) of magnetite from aqueous solutions of  $\text{Fe}^{3+}$  and  $\text{Fe}^{2+}$  ions in the presence of concentrated  $\text{NH}_4\text{OH}$  solution (25%)  $\rightarrow$  subdomain magnetite particles  $\rightarrow$  sterical stabilization (chemisorption of oleic acid;  $80\text{--}82^\circ\text{C}$ )  $\rightarrow$  phase separation  $\rightarrow$  magnetic decantation and repeated washing  $\rightarrow$  monolayer covered magnetite nanoparticles + free oleic acid  $\rightarrow$  extraction of monolayer covered magnetite nanoparticles (acetone added; flocculation)  $\rightarrow$  *stabilized magnetite nanoparticles*.

Cobalt ferrite and  $\gamma\text{-Fe}_2\text{O}_3$  nanoparticles were also prepared, but applying a somewhat different procedure and using NaOH in excess, instead of  $\text{NH}_4\text{OH}$ .

### DISPERSION OF MAGNETIC NANOPARTICLES – PREPARATION OF MAGNETIC NANOFLUIDS

*Non-polar carriers (hydrocarbons):* dispersion of oleic acid monolayer coated magnetite nanoparticles in various hydrocarbon (kerosene, toluene, cyclohexane, transformer oil, etc.) carriers at  $t \approx 120\text{--}130^\circ\text{C}$   $\rightarrow$  magnetic decantation/filtration  $\rightarrow$  repeated flocculation and redispersion of magnetic nanoparticles (elimination of free oleic acid; advanced purification process)  $\rightarrow$  *non-polar magnetic nanofluid*.

*Organic polar carriers (such as diesters, alcohols, ketones, amines, mixtures of various mineral and synthetic oils (e.g., high vacuum oils):* primary magnetic fluid on light hydrocarbon carrier  $\rightarrow$  repeated flocculation and redispersion of magnetic nanoparticles (elimination of free oleic acid; advanced purification)  $\rightarrow$  *monolayer stabilized magnetic nanoparticles*  $\rightarrow$  dispersion in polar solvent

(stabilization with secondary surfactant, *e.g.*, dodecylbenzenesulphonic acid, physically adsorbed to the first layer) → *polar magnetic nanofluid*.

The preparation of *water based magnetic fluids* follows a somewhat different route: coprecipitation of  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$  ions (excess of concentrated  $\text{NH}_4\text{OH}$ ; approx.  $80^\circ\text{C}$ ) → subdomain  $\text{Fe}_3\text{O}_4$  nanoparticles → repeated washing/purification → double layer sterical stabilization using dodecylbenzenesulphonic acid (DBS + DBS; at about  $80^\circ\text{C}$ ) → double layer sterical + electrostatically stabilized  $\text{Fe}_3\text{O}_4$  nanoparticles in water → magnetic decantation/purification → → low or medium concentration *water based magnetic nanofluid*.

The secondary DBS layer has the group  $-\text{SO}_3^-$  oriented towards the dispersion medium and it is covered with hydrated  $\text{NH}_4^+$  ions. It means that the degree of colloidal stability of water-based magnetic fluids depends on the pH value of the medium and that the *electrosteric* stabilization mechanism is specific mainly to water based magnetic fluids.

When lauric acid (LA) is used as double layer surfactant, then the preparation process is similar to that outlined for non-polar solvents, because in this case the coprecipitation step is followed also by phase separation. LA stabilized water based magnetic fluids are biocompatible.

By applying the above procedures, a wide variety of magnetic nanofluids were prepared on more than 50 different carrier liquids [11]. Specially tailored magnetic fluids were used also to prepare nano-microstructured magnetorheological fluids. In this case micrometer ranged iron particles are dispersed in a concentrated magnetic nanofluid [12], the stability of the suspension being ensured by covering the large Fe particles by magnetite nanoparticles [13].

### 3. CHARACTERIZATION OF MAGNETIC NANOFUIDS

#### 3.1. STRUCTURAL INVESTIGATIONS

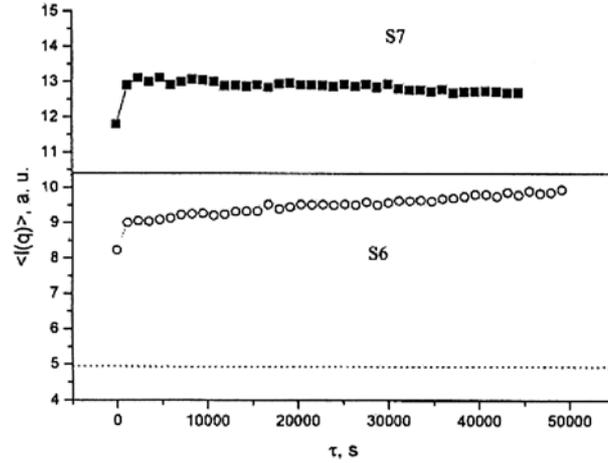
In the case of sterically stabilized nanoparticles in various carrier liquids, the type and quality of surfactants used, as well as the temperature of the medium will determine the efficiency of particle surface covering and, consequently, the balance between attractive and repulsive interactions between particles. The attractive interactions, when preponderant, may lead to various types of agglomerates, usually in the shape of linear chains quasi-parallel to the applied magnetic field or drop-like aggregates [14]. The agglomeration processes are not desired in the case of magnetic fluids used in most of the applications; therefore the characterization methods are mainly focused on these processes and on their consequences in the macroscopic behaviour of the fluids.

One of the most efficient methods of nanostructural investigation is based on small angle neutron scattering (SANS). This method is applied to reveal structural features at the scale of 1–100 nm. Indeed, the size of magnetic particles in magnetic fluids (3–15 nm), as well as the characteristic correlation length between particles are mostly in this dimensional range.

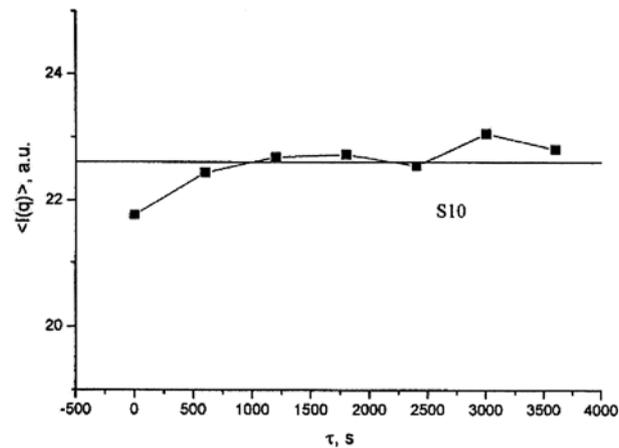
Among the non-polar magnetic fluids, the benzene based samples are the most stable ones. A deuterated benzene based version of this type of magnetic nanofluid of high volumic concentration (19%) was supposed to SANS investigation [15] carried out on the small angle diffractometer at the Research Institute for Solid State Physics and Optics-Budapest Neutron Center (BNC). The density of the sample was 1.724 g/cm<sup>3</sup> and its saturation magnetization 840 G. The original fluid was diluted to the magnetite volumic concentration values 9.5, 6.3, 3.8 and 1.1 vol%. The experimental scattering intensity curves  $I=f(q)$  in the  $q$ -range 0.2–5 nm<sup>-1</sup> were fitted with the model expression of SANS intensity of noninteracting polydisperse spherical homogeneous magnetic particles covered by a homogeneous shell. The fit revealed a significant decrease, from 1.85 nm to 1.05 nm, in the thickness of the surfactant shell with the increase of the magnetite concentration, *i.e.* with the decrease of the mean interparticle distance. This interesting result can be explained by the interlacing of surfactant tails on the surface of magnetite particles caused by the interparticle interaction.

The problem of particle interactions is even better revealed by SANS investigations on magnetic fluids situated in intense magnetic field. This kind of investigations performed recently referred to two kind of double layer surfactated polar samples, in particular on water and pentanol based magnetic fluids. The pentanol based samples prepared according to [8] proved to be of high colloidal stability even when there were supposed to ultracentrifugation [16]. On the other hand, water based samples are known to be less stable, due to pre-existing agglomerates formed during preparation, which develop into large, drop-like agglomerates under the influence of the applied magnetic field [14], regardless to the mechanism of stabilization (steric and/or electrostatic). The SANS experiments performed at BNC [10] referred to water and pentanol based samples supposed to an intense applied magnetic field of magnetic induction up to 1.2 T, which saturated the samples. The time of increase and decrease of the magnetic field was of the order of seconds. Measurements were made in conditions “no field” (1200 s), “field on” (1200 s) and “field off” (several expositions 1200 s each). To follow the field induced changes in the aggregation of particles, the scattering intensity was averaged over a  $q$ -interval 0.2–0.7 nm<sup>-1</sup>. The mean intensity as a function of time is given in Fig. 1 [10] for a water based and for a pentanol based sample, approximately of the same magnetization (particle volume fraction). The mean intensity values corresponding to the initial stage of samples, before the magnetic field was applied, are also shown (solid lines).

Fig. 1. – Mean intensity  $\langle I \rangle$  as a function of time  $\tau$  after demagnetization for (a) two water based samples (S6 (LA + DBS) (14.3 kA/m); S7 (LA + DBS) (18.7 kA/m)) and (b) a pentanol based sample (S10 (DBS + DBS) (22.3 kA/m)). Horizontal lines in the graphs correspond to the mean intensity value of the initial magnetic fluid samples before they were set in the magnetic field: ■, ○ applied magnetic field ( $B = 1.2$  T); — zero field ( $B = 0$  T).



(a)



(b)

The field induced agglomerate formation in the case of water based samples is clearly evidenced by the difference between the curves corresponding to “no field” (solid line) and “field off” stages. On the contrary, the highly stable pentanol based sample did not show such changes, *i.e.* practically no agglomerates were formed under the action of the field. A comparative SANS investigation of various water based samples, with different surfactant layers, LA + LA (1), LA + DBS (2) and DBS + DBS (3), was performed at the Geestacht Neutron Facility of GKSS [17], at temperature values 25, 50 and 70°C to see how the particle structures changes with temperature. Preliminary data analysis show that the SANS signal from sample 1 (LA + LA) is significantly smaller in comparison with the other two samples. Nevertheless, the character of the scattering curves from samples 1 and 3 are quite similar, despite of the large

difference in the magnitude of the mean scattering. Changes of the scattering curves with the temperature denote that the structuring process is temperature-dependent. The same effect was evidenced in magneto-optical investigations on water-based magnetic fluids [18].

### 3.2. MAGNETIC PROPERTIES

Magnetization curves can be extensively used for the study of both particle interactions and agglomerate formation, processes which strongly influence the rheological and magneto-rheological behaviour of magnetic fluids. Saturation magnetization ( $M_s$ ), initial susceptibility ( $\chi_i$ ), full magnetization curves ( $M = M(H)$  or  $M/M_s(H)$ , ( $H$  – intensity of applied magnetic field) and magneto-granulometric analysis (mean magnetic diameter  $\langle D_m \rangle$  and standard deviation  $\sigma$ ), at various values of the volumic concentration of magnetic nanoparticles, give an insight on microstructural characteristics of various samples to be compared [16, 19–21]. For example, the initial susceptibility is influenced by particle diameter and size distribution, particle interactions, existence of preformed aggregates during the preparation process and aggregate formation at zero field or induced by the applied magnetic field. As it was shown in detail in [22], the comparison of the dependence of the initial susceptibility,  $\chi_i$ , on the physical volume fraction,  $\Phi$ , of magnetic nanoparticles for samples of different types of magnetic fluids, reveals interesting microstructural aspects. The initial susceptibility in the framework of the thermodynamic perturbation theory (TPT) [23] is given by:

$$\chi_i = \chi_{iL} \left( 1 + \frac{1}{3} \chi_{iL} \right) \quad (1)$$

where

$$\chi_{iL} = \frac{\mu_o \pi M_d^2 D_m^3 \Phi_m}{18 k_B T} \quad (2)$$

Here  $M = M_s L(\xi)$ , where  $L(\xi)$  is the Langevin function, with  $\xi = \mu_o m H / (k_B T)$ , where  $M_d$  is the spontaneous magnetization of particles,  $\Phi_m = p_m \Phi$  is the “magnetic” volume fraction ( $\Phi$  – physical volume fraction and  $m$  – magnetic moment of particles),  $D_m$  the magnetic diameter of particles,  $k_B T$  is the thermal energy and  $\mu_o$  the permeability of vacuum. Equations (1) and (2) show the strong influence of the mean “magnetic” volume/diameter of particles, as well as of the size distribution on the low field part of the magnetization curve. In particular, particle agglomerates, which behave as large particles will determine this part of the magnetization curve.

Formula (1) may be extended in the framework of the same TPT for concentrated magnetic fluids, applying the second order approximation [23]:

$$\chi_i = \chi_{iL} \left( 1 + \frac{1}{3} \chi_{iL} + \frac{1}{144} \chi_{iL}^2 \right) \quad (3)$$

Composition details, in particular the quality of the surfactant used, as well as its particular adsorption properties to the nanoparticle surface, influence particle agglomeration processes. It was shown in [22] that double layer sterically stabilised pentanol magnetic fluids have smaller initial susceptibility, compared to other, less well stabilized samples of the same concentration and quasilinear  $\chi_i = \chi_i(\Phi)$  dependence, at least for small  $\Phi$  values, *i.e.* agglomerates are practically absent in this case. This conclusion was supported by ultracentrifugation/sedimentation velocity tests [16] and by comparison with theoretical models [22], in particular with the second order susceptibility formula obtained by Ivanov and Kuznetsova [23] in the framework of the thermodynamic perturbation theory.

The saturation magnetization of various magnetic fluids with non-polar and polar carrier liquids and magnetite nanoparticles, prepared according the procedures summarized in section 2, attain 79.6–95.5 kA/m.

In the above context, it is interesting to compare the nondimensional magnetization curves determined with a vibrating sample magnetometer (VSM 880, DMS/ADE Technologies, USA), in particular in the low field region (Fig. 2), for two different kind of polar samples, water based magnetic fluids with DBS + DBS and LA + LA surfactant layers, as well as a pentanol based sample with DBS + DBS surface coating. In good correlation with SANS investigations mentioned above, the LA + LA coating proved to be more efficient in stabilizing the system, in comparison with DBS + DBS double layer.

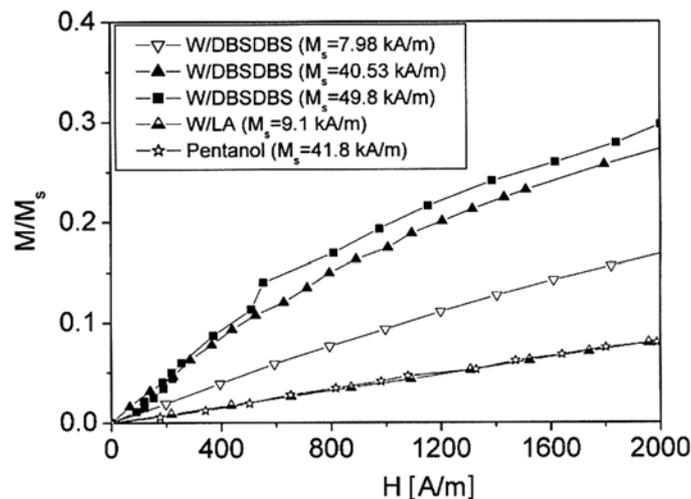


Fig. 2. – Nondimensional magnetization  $M/M_s$  at low field for water based samples, compared to a pentanol based sample.

Indeed, the low-field magnetization curve for the LA stabilized sample lies well below the curve corresponding to the DBS stabilized one, practically being superposed with the nondimensional magnetization curve of the highly stable pentanol based sample [22]. Moreover, the DBS stabilized water based samples have non-linear  $M/M_s = F(H)$  dependence even in the low field region, which evidence a significant difference compared to the ideal Langevin behaviour, due to the presence of particle agglomerates. These agglomerates strongly influence, as will be shown below, the flow properties of magnetic fluids.

### 3.3. RHEOLOGICAL AND MAGNETORHEOLOGICAL BEHAVIOUR

The dependence of nondimensional viscosity,  $\eta/\eta_o$ , where  $\eta$  is dynamic viscosity of the magnetic fluid and  $\eta_o$  is the dynamic viscosity of the pentanol carrier liquid, on the solid particle volume fraction,  $\phi_p$ , may be determined using the Vand formula, as shown in [21]. In order to determine the hydrodynamic volume fraction,  $\phi_h$ , *i.e.* the effective volume fraction of the double-layer-covered  $\text{Fe}_3\text{O}_4$  nanoparticles, the experimental data were fitted to the Vand formula using the fit parameter  $p = \phi_h / \phi_p$ :

$$\eta/\eta_o = \exp\left[\left(2.5p\phi_p + 2.7p^2\phi_p^2\right)\right]/(1 - 0.609p\phi_p) \quad (4)$$

The fitted  $\eta/\eta_o = f(\phi_s)$  curves at various temperatures, together with the detailed results of the fits with the formulae of Vand, Krieger-Dougherty, Quemada, Chong, Rosensweig and Chow, for pentanol based samples, as well as other magnetic fluids, may be found in [19–22, 26]. Using the fitted  $p$  values, the effective mean surfactant layer thickness may be obtained,  $\delta = (p^{1/3} - 1)D/2$ .

The values of the maximum hydrodynamic volume fraction,  $\phi_m$ , were determined by fitting the data to the well-known two-parameter formula of Krieger and Dougherty.

$$\eta/\eta_o = (1 - \phi_h / \phi_m)^{-[\eta]\phi_m} \quad (5)$$

where  $[\eta]$  is the intrinsic viscosity.

In the case of highly stable pentanol based magnetic fluid samples two fits are presented in Figs. 3 and 4 [26]. In the fit of Fig. 3 it was supposed that the nanoparticles are of spherical shape, *i.e.* the intrinsic viscosity is 2.5, while in Fig. 4 the fit parameter was the intrinsic viscosity itself. In this latter case, the maximum packing fraction was taken from a fit to the formula of Quemada [26]. The intrinsic viscosity  $[\eta]$  values obtained from the fits are clearly different from that corresponding to spherically shaped particles, resulting  $[\eta] = 2.92$ . Also, the

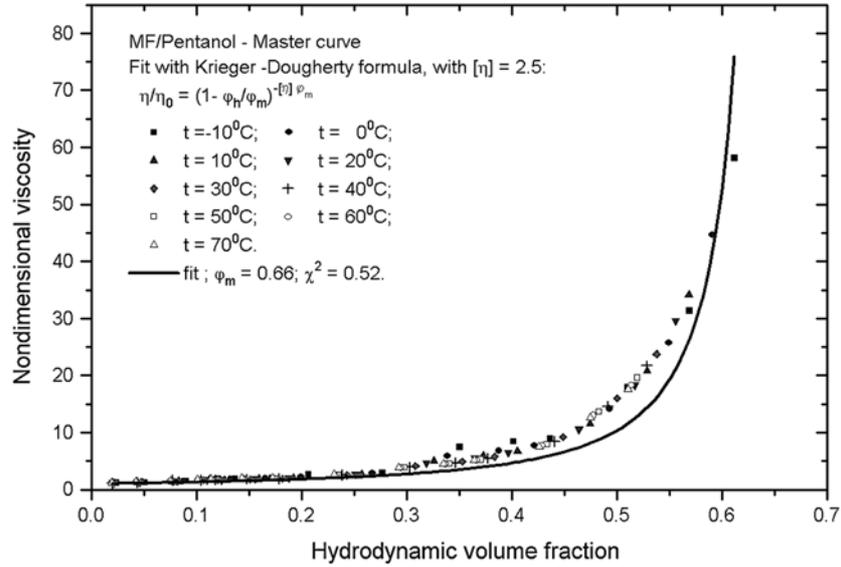


Fig. 3. – Nondimensional viscosity vs. hydrodynamic volume fraction of surfactant covered magnetite nanoparticles in pentanol carrier. Fit to Krieger-Dougherty formula (nanoparticles are supposed to be of spherical shape; intrinsic viscosity 2.5)).

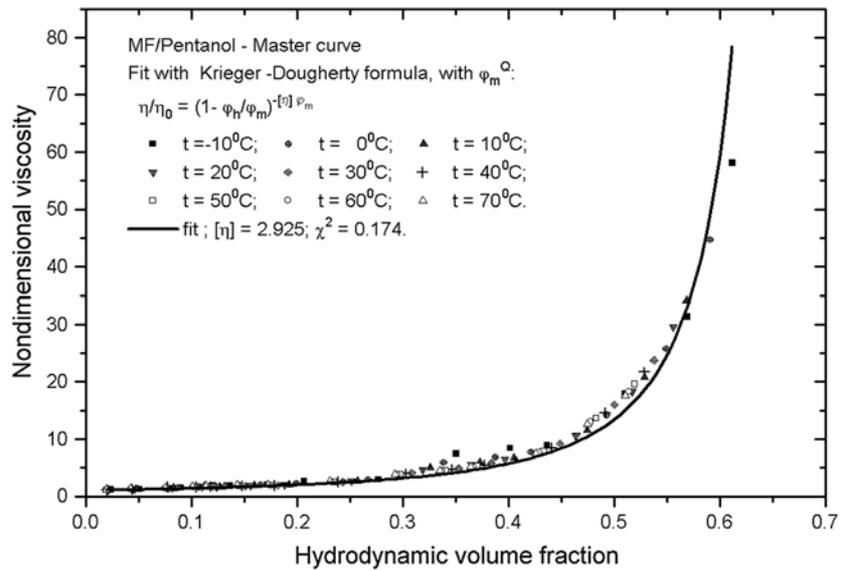


Fig. 4. – Nondimensional viscosity vs. hydrodynamic volume fraction of surfactant covered magnetite nanoparticles in pentanol carrier. Fit to Krieger-Dougherty formula (intrinsic viscosity is a fitted parameter).

fitted data evidenced that  $p$  and consequently  $\delta$ ,  $\varphi_m$  and  $[\eta]$ , are slightly temperature dependent. Indeed, the effective surfactant layer thickness,  $\delta$ , depends on the temperature and has greater values at lower temperatures, especially because the physically adsorbed secondary surfactant layer is more influenced by the thermal motion.

In the refs. [24, 25] Chow performed a thorough theoretical analysis of concentrated suspensions, taking into account the contribution of many-body particle interactions on the effective viscosity. On the basis of a liquid lattice model, the low-shear limiting viscosity resulted as

$$\frac{\eta}{\eta_o} = \exp\left(\frac{2.5\varphi_h}{1-\varphi_h}\right) + \frac{A\varphi_h^2}{1-A\varphi_h^2\varphi_m} \quad (6)$$

where  $A$  is the coupling coefficient. Without considering dipole-dipole type interactions between particles, the theoretical value of  $A$  was determined to be 4.67.

The theoretical formula (eq. 6) obtained by Chow proved to be well fitted by viscosity data for various magnetic fluids, as it follows from detailed investigations on various type of magnetic fluids [26]. The fitted values of  $A$  are close to the theoretical one for  $\varphi_h \leq 0.45$ . At higher values of the hydrodynamic volume fraction, the resulting  $A$  value is lower, evidencing the role of dipolar interactions at close packing.

The results of a fit of all the viscosity data corresponding to the temperature interval  $-10-70^\circ\text{C}$  and up to the highest hydrodynamic volume fraction,  $\varphi_m \sim 0.6$ , are shown in Fig. 5. The experimental data are well fitted by the Chow formula (eq. 3), the resulting overall coupling coefficient being 3.63. This fit and several others given in [26] show that  $A$  is smaller than the theoretical value of 4.67 at lower temperatures and at close packing of particles, when the role of magnetic interactions between particles can not be neglected, even in the case of a magnetic fluid of very high degree of colloidal stability. Note, that at  $t \geq 50^\circ\text{C}$ , the fitted values of  $A$  approach the theoretical one, the increased thermal motion diminishing the influence of dipolar interactions.

Under the influence of magnetic field, magnetic fluids increase their effective viscosity owing to the supplementary dissipation due to the motion of particles relative to the surrounding carrier liquid.

The magnetoviscos effect is described by the model developed by Shliomis [27], but its validity is limited to a very low volumic concentration of particles even if we take into account the size distribution of the particles and the Shliomis diameter, as in the generalized formula proposed in [20].

The intensity of the magnetoviscos effect [28] is strongly dependent on various microstructural processes, especially on those relating to agglomerates.

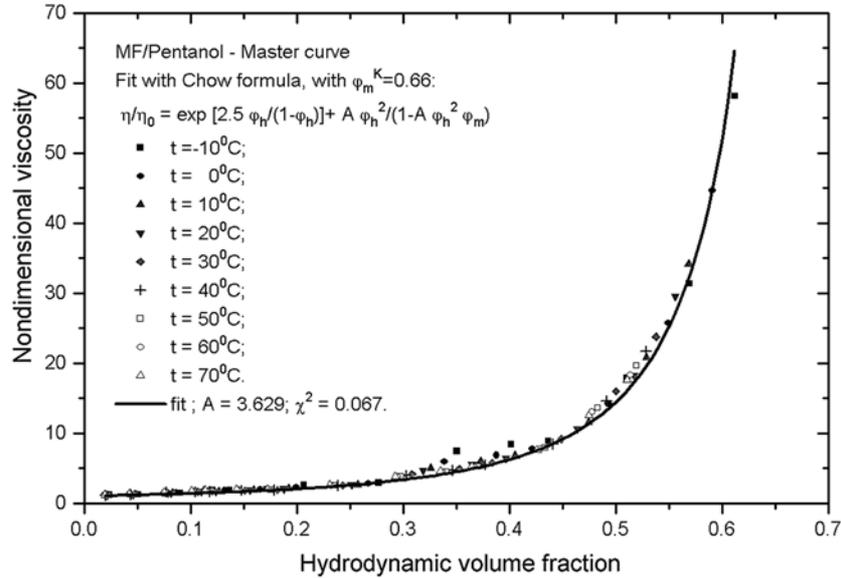


Fig. 5. – Nondimensional viscosity vs. hydrodynamic volume fraction of surfactant covered magnetite nanoparticles in pentanol carrier. Fit to Chow formula.

Incomplete surfactant covering of particles initiates the formation of agglomerates, which significantly change the behaviour of magnetic fluids in a magnetic field.

The magnetic field induced changes of flow properties are well illustrated by the flow curves determined for a highly polar, methyl-ethyl-ketone (MEK) based magnetic fluid, in comparison with an i-butanol (i-But) based, also polar magnetic fluid [29].

Increasing the magnetic induction the Newtonian character of the flow changes significantly and becomes non-Newtonian (Fig. 6). The effective viscosity vs. shear rate curves, under the influence of applied magnetic field, were measured using a MCR 300 type PHYSICA rheometer, with plate-plate magnetorheological cell. The shear rate dependence of the effective viscosity of the MEK based sample show a strongly non-Newtonian character, compared to the practically Newtonian behaviour of the i-But magnetic fluid.

The relative increase of effective viscosity,  $[\eta(B) - \eta(0)]/\eta(0)$ , is a very useful quantity in describing the magnetoviscos effect [28]. In [28] the significant role of the microscopic make-up of ferrofluids on their flow behaviour is argued by detailed experimental data. From the measured data for the MEK and i-But samples, the relative increase of effective viscosity is given in Fig. 7 for two different shear rate values. The viscosity increase is practically zero for the highly stable i-But sample. However, for the MEK based sample, the relative increase is more than two-fold at the lower shear rate value. Increasing the shear rate, the agglomerates are progressively destroyed and the effective viscosity

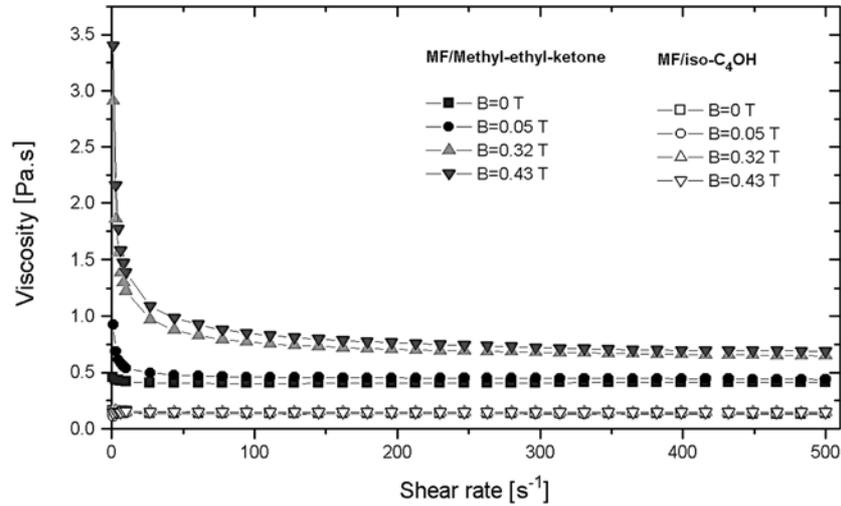


Fig. 6. – Viscosity vs. shear rate at various values of magnetic induction  $B$  for magnetic fluids with methyl-ethyl-ketone and i-butanol as carrier liquids: stabilizant double layer DBS + DBS; saturation magnetization of samples  $\approx 39.8$  kA/m (MR cell with plate-plate geometry).

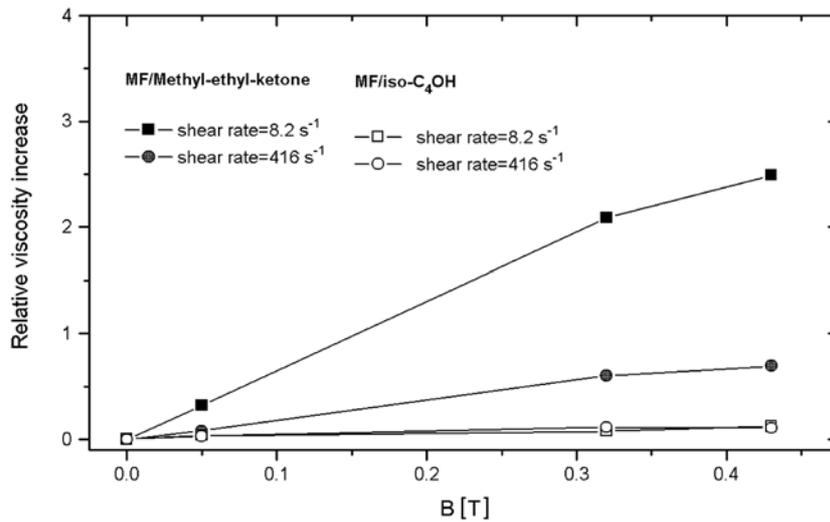


Fig. 7. – Relative increase of effective viscosity vs. magnetic induction of the applied magnetic field: magnetic fluids with methyl-ethyl-ketone and i-butanol as carrier liquids; stabilizant double layer DBS + DBS; saturation magnetization of samples  $\approx 39.8$  kA/m (MR cell with plate-plate geometry).

change reduces. The magnetorheological effect observed for the two magnetic fluids clearly evidence the existing differences in colloidal stability of samples.

The double surfactant layer of DBS is much more efficient in the case of i-butanol, then for the much more polar MEK carrier.

#### 4. APPLICATIONS

The great variety of magnetic nanofluids prepared may be easily tailored for many of the applications outlined in [4–6]. The new kind of concentrated magnetic fluids presented in this paper, in particular on strongly polar carriers, such as water, methyl-ethyl-ketone or short chain length alcohols, are envisaged both for technological and biomedical researches and applications.

Technical grade DBS stabilized water based magnetic nanofluids are rather promising as magnetically controlled heat transfer agents, both for terrestrial and space applications [30].

Biocompatible water based magnetic fluids with lauric acid surfacted magnetite nanoparticles, are especially interesting for immobilization of biomolecules and for magnetic drug targeting [31]. Lanolin and water based magnetic fluids were used to prepare magnetizable nanocomposites, which showed prolonged protective effect against UV radiations (protective sunscreen) in systematic experiments on animals [32].

The highly polar MEK based magnetic fluids were used to obtain a large variety of polymeric nanocomposites with improved mechanical and magnetic properties [33], with applications foreseen for the aeronautical industry.

The association of conducting polymers, like polypyrrole, with water based magnetite nanofluids, resulting in electroconductive and magnetizable PPY-Fe<sub>3</sub>O<sub>4</sub> nanocomposites, gives rise to new type of nanocomposites with controllable properties [34].

#### 5. CONCLUSIONS

Magnetic nanofluids are a well defined category of magnetically controllable nanomaterials with fluid properties.

Chemical synthesis of magnetic nanofluids on strongly polar carrier liquids proved to be an efficient and reproducible way to obtain new type of magnetic fluids with high degree of colloidal stability. Composition details and stabilization mechanism determine the magnetic, rheological and magnetorheological properties of magnetic nanofluids. Magnetic fluids on water and strongly polar organic carriers are foreseen to be used as magnetically controlled cooling agents, as well as basic components of nanocomposites for technological and biomedical applications.

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