The Effect of a Magnetic Field on the Rheological Properties of Iron - Aerosil - Glycerol Suspensions

S. A. Vshivkov, A. G. Galyas, and A.Yu. Oznobikhin

Ural Federal University, Ekaterinburg, Russia

ABSTRACT

The viscosity of a suspension consisting of iron nanoparticles, aerosol and glycerol has been studied under the conditions of a rotational flow in the presence and absence of a magnetic field. It was found that viscosity increases 40 times in the presence of magnetic field.

INTRODUCTION

An increase of magnetic fluid viscosity[1] in a magnetic field (the magnetorheological effect) was experimentally discovered in the 1950s for systems based on iron carbonyl and iron oxide[2]. This phenomenon was then studied in a number of works[1, 3-6]. It was found that resting compositions are structured a result of interparticle magnetic dipole interactions and the orientation of anisodiametric structural elements along magnetic field lines. Under the effect of shear flow, aggregates are disrupted and this process is intensified with deformation rate. Each combination of preset parameters (dispersion medium viscosity, magnetic properties of particles, field strength, and deformation rate) corresponds to a specific combination of structural elements and their relative arrangement

The aim of this work was to study the concentration dependence of the effect of permanent magnetic field strength on the viscosity of an iron–aerosil–glycerol magnetorheological suspension under the conditions of a rotational flow.

EXPERIMENTAL

A suspension of silica (SiO_2) and iron (Fe) nanoparticles in glycerol was studied as a magnetic fluid. Iron nanopowder colored black (weight-average particle diameter of 150 nm, specific surface area Ssp =8.3 m^2/g, and density ρ = 7.874 g/cm^3) was prepared in the Institute of Electrophysics, Ural Branch, Russian Academy of Sciences. Aerosil of the A-175 brand-colloidal silica (weight-average particle diameter of 250 nm and ρ=2.2 g/cm^3) was produced at the Pilot Plant, Institute of Surface Chemistry, National Academy of Sciences of Ukraine. Glycerol (analytical grade, Vekton, ρ=1.261 g/cm^3) was used as a dispersion medium. Suspensions were prepared by mixing glycerol with aerosil nanoparticles. The concentration of silica nanoparticles in the system was constant and equal to 10 wt %. Dispersions of iron nanoparticles with the concentrations of 0.5, 1.0, 1.5, and 2.0 wt % were prepared by adding them to the suspensions. The viscosities of the dispersions were measured us in a modified Rheotest RN 4.1 rheometer equipped with a coaxial cylindrical working unit made of a weakly magnetic material - brass. Magnetic field was generated using the following magnetic systems: (1) a system generating a permanent magnetic field with the average strength of 290 kA/m and field lines directed perpendicularly to the rotor-rotation axis and (2) one generating a permanent magnetic field with the average strength of 280 kA/m and field lines directed parallel to the rotor-rotation axis. The relative measurement error was no longer than 1.5

%. Distribution of magnetic field strength in the working unit is represented on the Fig. 1.

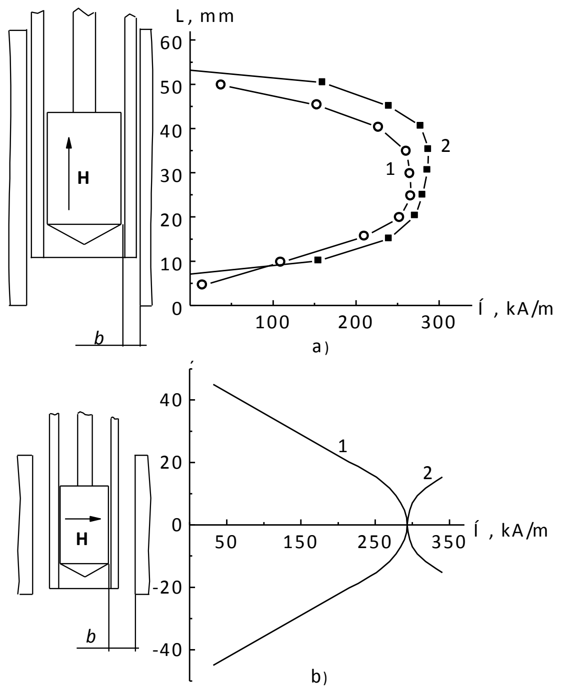

Figure 1. Panel (a): distributions of magnetic field strength (1) along the rotor-rotation axis and (2) at a distance of 2 mm from the surface of tne permanent magnet; Panel (b): strength distributios of magnetic fields (1) parallel and (2) perpendicular to the rotation axis. See text for explanations.

For the geometry shown in Fig. 2a, distance *b* from the center of the gap between the rotor and the stator to the magnet surface was 3.95 mm. the width of the working gap field with the fluid was 0.67 mm. The effective magnetic field strength in the center of the gapbetween the rotor and stator was 280 kA/m. The nonuniformity of the magnetic field strength throughout the gap cross section was neglected because of the smallness of the latter. For the geometry depicted in the Fig. 2b, *b*=7.54 mm. the effective effective strength of the magnetic field in the center of the gap between the rotor and stator was 290kA/m.

The working unit with the dispersion was exposed to a magnetic field at T=295 K for 20 min and the viscositu was measured in the magnetic field? While shear rate $\dot{\gamma}$ was gradually increased from 0 to 40 s^{-1} for 900 s.

The metal rotor rotating in a magnetic field may be considered to be a current generator closed on itself. The operation of this generator induces so-called braking electromagnetic moment[7] *M*e. To take the electromagnetic moment into account, a correction dependence of the shear stress on the shear rate in the working unit with cylinder surfaces separated by air was plotted. Analogous measurements were performed for water and DMF. All data on the electromagnetic moment coincided with each other. The real shear stresses for the dispersions were obtained as differences between the measured values and the values determined from the correction curve for the same shear rates. When the magnetic field lines were orientated along the rotor-rotation axis, the magnetic flux through the vertical section of the rotor was equal to zero. Hence, the electromagnetic moment was also zero.

RESULTS AND DISCUSSION

At a low shear rate (0-2 s^{-1}), the effect of a magnetic field on the suspension viscosity dominates over the effect of a mechanical stress field, and the viscosity increases by more than 40 times (Fig. 2a). In this case, the field oriented perpendicular to the rotor-rotation axis affects the system viscosity four times as strongly as the field oriented parallel to the rotation axis does.

At a high shear rate (15 s^{-1}), the effect of the mechanical stress field prevails, viscosity increases by a factor as small as 1.4, and the concentration dependence of the viscosity in a magnetic field is described by a curve passing through a maximum (Fig. 2b). At the same time, the direction of the field lines has in fact no effect on the viscosity.

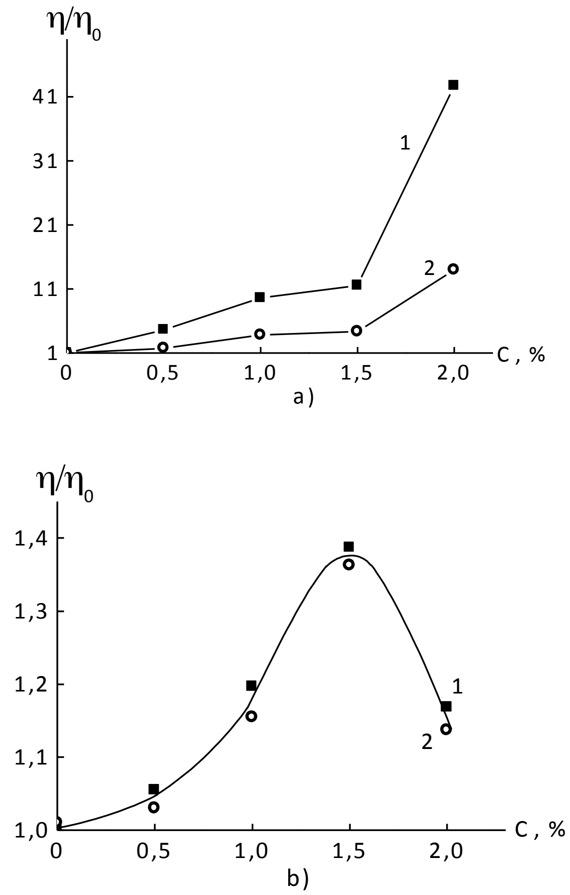

Figure 2. Concentration dependences of relative viscosity of a suspension in magnetis fields oriented (1) perpendicularly and (2) parallel to the rotor-rotation axis: $\dot{\gamma}$=0.5 s^{-1} (a), $\dot{\gamma}$=15 s^{-1} (b).

Thus, the boundary conditions of the influence of the magnetic and mechanical fields on the rheological properties of ferrofluids have been determined that may be used in the technology of new magnetosensitive nanomaterials.

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