MAGNETOVISCOUS EFFECTS IN FERROFLUIDS

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Abstract
Suspensions of magnetic particles with diameters in the nanometer range exhibit longterm sedimentation stability as well as the possibility of magnetic field induced control of their properties and flow. One of the most famous field induced effects is the change of viscosity of the fluids due to the action of magnetic influences. An explanation of these effects on basis of microscopic models is a challenging field of actual experimental and theoretical research. Within this article the state of knowledge on magnetoviscous effects in magnetic fluids will be summarized and in particular the experimental methods used to obtain related results will be discussed.

Zusammenfassung
Suspensionen nanometergrosser magnetischer Partikel können langzeitstabil erzeugt werden und gestatten die Kontrolle ihrer Eigenschaften und Strömungen durch moderate Magnetfelder. Einer der bekanntesten magnetischen Effekte, der in derartigen Suspensionen hervorgerufen werden kann, ist die Änderung ihrer viskosen Eigenschaften in Gegenwart von Magnetfeldern. Die Frage nach der mikroskopischen Ursache dieser Effekte ist ein Gebiet aktueller experimenteller wie auch theoretischer Forschung. Im Rahmen dieses Beitrags soll der Stand der Kenntnisse über magnetoviskose Effekte in magnetischen Flüssigkeiten zusammengefaflt werden. Insbesondere sollen dabei auch die experimentellen Methoden zur Bestimmung der Feldabhängigkeit der Viskosität diskutiert werden.

Résumé
Les suspensions de particules magnétiques possèdant des diamètres de l’ordre du nanomètre présentent une stabilité de sédimentation a long terme. De plus, il est possible de contrôler leur propriétés et leur écoulement au moyen de l’application d’un champ magnétique. L’un des effets les plus célèbres, induit par le champ, est le changement de viscosité des fluides, du à l’action des influences magnétiques. Une explication de ces effets, sur la base de modèles microscopiques, est un domaine de recherches qui présente,de nos jours, un défi, tant du point de vue théorique qu’expérimental. Dans cet article, l’état des connaissances des effets magnétovisqueux dans les fluides magnétiques est résumé, et en particulier, les méthodes expérimentales utilisées sont discutées.

Key words: Ferrofluid, magnetoviscous effect, chain formation, magnetorheological effect

1 INTRODUCTION

The material in the scope of this review are suspensions of magnetic nanoparticles in appropriate carrier liquids. The mean diameter of the particles is about 10 nm. Thus – from a magnetic point of view – the particles can be treated as single magnetic domains [1]. Due to their small size, destabilization of the suspension due to sedimentation in the gravitational field, demixing in magnetic field gradients and magnetic agglomeration can be neglected. In contrast, v.d. Waals interaction between the particles could not be counteracted by thermal energy and thus would force irreversible agglomeration of the particles. To avoid this kind of destabilization, the particles have to be covered with a surfactant of long chained molecules. The dielectric properties of the surfactant have to fit those of the carrier liquid to avoid van der Waals interaction between the surfactant layers. Appropriate choice of the surfactant provides a repulsive potential between the particles due to steric repulsion of the coating layers. Therefore a 2 nm thick coating can produce a potential barrier ensuring long term stability of the suspension. After the first synthesis of such so called ferrofluids by Papel [2] intense research and the development of numerous applications [3] started. Nowadays ferrofluids are available, which exhibit long term stability for more than 10 years. Usually magnetite (Fe_3O_4) is used as magnetic component for commercially available ferrofluids. In experimental fluids other interesting magnetic materials like mixed ferrites [4, 5] or cobalt [6] are used. The choice of the carrier liquid depends on the intended use of the fluid. Various oils, water and different organic carriers are actually available. The volume concentration of the magnetic component can go up to 15 vol.%.

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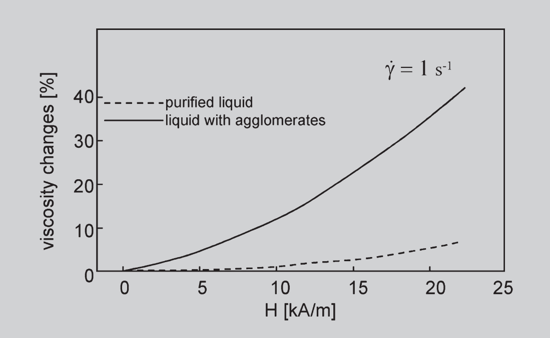

Figure 7:
Relative change of viscosity for two fluids with identical magnetic concentration and different amount of primary agglomerates.

ing hypothesis it was assumed in [32] that primary agglomerates [33] – dimers of particles with common surfactant layer – dominate the magnetoviscous behavior. To prove this, we have recently carried out experiments using fluids with variable agglomerate content [34]. The overall magnetic concentration of all these liquids has been held identical to avoid changes of interaction due to variation of concentration.

These experiments showed, that decreasing content of primary agglomerates dramatically reduces the magnetoviscous effect (Fig. 7). Thus it can now be stated that the content of agglomerates, formed during the production process of the fluids is of significant importance for their magnetoviscous properties.

4 CONCLUSION AND OUTLOOK

It has been discussed in detail that suspensions of magnetic nanoparticles exhibit strong changes of their viscous behavior due to action of magnetic fields. It has been shown that these changes can be explained in a single particle model as long as highly diluted suspensions of magnetically hard particles are considered. In this case changes of viscosity are due to the hindrance of free rotation of the particles in a static magnetic field or due to driving of the particles by alternating fields.

As soon as concentrated liquids are considered, interaction of the particles has to be taken into account and formation and breakage of chains dominates the magnetoviscous behavior. To explain these effects in fluids with a major amount of magnetically weak particles, the influence of primary agglomerates has been studied. Presently it seems that these dimers dominate the magnetoviscous properties of such fluids.

In the future, a detailed understanding of the microscopic properties of the fluids and the structural reasons for magnetoviscous effects will have to be a goal of research. From the theoretical side, Monte Carlo simulations and non equilibrium molecular dynamics simulations will have to be used to create appropriate models for the fluids. From the experimental side a connection of macroscopic measurements with direct microscopic investigations, e.g. using neutron diffraction techniques will have to be considered. Besides, the development of new fluids containing particles with high spontaneous magnetization and high crystallographic anisotropy will open new possibilities to enhance the magnetoviscous effects, finally making the fluids appropriate for the design of new ferrofluid applications.

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