Review of the Electrorheological (Er) Effect of Polyurethane-based Er Fluids

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Abstract:
Electrorheological fluids (ERF) change viscosity when an electric field is applied. A special type of ERF consists of polyurethane particles which are doped with Li^+ and /or Zn^{2+} cations and suspended in silicone oil. This article gives an overview of the temperature dependent behavior of the ER effect for these fluids and describes the basic principles how this is explained. Chemical analyses provide information as a basis for a polarization model in several dimensions down to molecular size.

Zusammenfassung:
Elektrorheologische Flüssigkeiten (ERF) ändern bei angelegtem elektrischen Feld ihre Viskosität. Eine bestimmte Art von ERF besteht aus Silikonöl und darin suspendierten Polyurethanpartikeln, welche mit Li^+- und /oder Zn^{2+}-Kationen dotiert sind. Der Artikel gibt einen Überblick über das temperaturabhängige Verhalten des ER-Effektes dieser Flüssigkeiten und beschreibt Grundprinzipien, wie dieser Effekt erklärt werden kann. Die durchgeführten chemischen Analysen dienen als Basis für ein Polarisationsmodell in verschiedenen Dimensionen bis auf Molekülgröße

Résumé:
Les fluides électrorhéologiques (ERF) voient leur viscosité modifiée lors de l'application d'un champ électrique. Il existe un type d'ERF, composé de particules de polyuréthane en suspension dans de l'huile de silicone, lesquelles particules sont dopées de cations Li^+ ou Zn^{2+}. Cet article présente un aperçu du comportement de l'effet ER de ces fluides en fonction de la température, et décrit les principes de base, qui permettent d'expliquer cet effet. Les analyses chimiques effectuées constituent la base d'un modèle de polarisation dans plusieurs dimensions allant jusqu'à la taille d'une molécule.

Key words: electrorheological fluids, viscosity-temperature dependence, polyurethan-based ER suspensions, polarization model

1   INTRODUCTION

Electrorheological fluids (ERF) as well as magnetorheological fluids (MRF) are both members of the group of smart fluids (Figure 1). The essential ERF attribute is controllable viscosity from non-viscous to solid when exposed to an electric field. This is a reversible process with a reaction time in the millisecond range. This characteristic may be used for the control of damper characteristics, of the pressure and volumetric flow in hydraulic circuits as well as for the torque transfer in clutches.

Since the discovery of the electrorheological effect by Winslow [1] ERF have been the subject of continuing research. Even after all the progress made, however, some unresolved issues remain [2]. This paper should help to describe the temperature dependent behavior of polyurethane-based ER fluids, with special consideration of the chemical processes occurring during the polarization of ERF.

ER suspensions consist of polarizable solid particles with a comparatively high relative dielectric constant which are dispersed in a supporting medium of low electrical conductivity and low relative dielectric constant. Typical supporting media are for example light oils, diethers, paraffins, aromatic hydrocarbons or silicone oils. Various types of polarizable solid particles may be used, including metal oxides, silica anhydrides or polymers with metal ions dissolved therein.

In the absence of an applied electric field (E = 0), the rheological behavior of ER suspensions corresponds to the behavior of Newtonian fluids, i.e. the shear stress τ is linearly proportional to the shear rate D, with the proportionality factor η

donors). Since in the present case the respective base for complexing is identical (oxygen in the polyether would be considered a hard base) the differences are due to the cation properties. Zn^{2+} should be considered a soft cation (comparably high ionic radius: 0.74 Å). Li^+ would be considered a hard cation (comparably low ionic radius: 0.68 Å) [18]. Thus, the lithium complex has to be considered more stable when compared to the zinc complex, a fact contributing to the strength of the ER effect. A more distinctive separation of charges in the Li^+-oxygen complex compared to the Zn^{2+}-oxygen complex provides a higher potential for polarization. The ion size is an additional influence on the ER properties with respect to a possible ion displacement. A smaller cation provides better conditions for a displacement within its coordination sphere. This results in an improved polarizability.

These effects are considered as the reasons why the lithium-containing ER suspension already shows a comparably high ER effect at low temperatures. The increase of the ER effect with increasing temperature is attributed to the properties of the polymer matrix. An interesting phenomenon occurs when the viscosity shows higher values for the 50:50 mixture compared to the single suspensions A and B. At low temperatures close to the maximum of the *V-T*-curve the polarizability of lithium-doped particles leads to good catenation. These lithium-doped particles may act as bridges for the zinc-doped particles which allows for improved low temperature catenation. At high temperatures close to the maximum of the *V-T*-curve the formed chains of zinc-doped particles may suppress the beginning electric conductivity of the lithium doped ones.

5.3 MODEL-TYPE SUMMARY DESCRIBING THE ER EFFECT

A model describing the ER effect of polyurethane based ERF has to cover several dimensions down to molecular size. In the micrometer scale polarized polyurethane particles show catenation. Figure 12 shows a schematic of the processes occurring in a polyurethane particle which result in the polarization of the latter when exposed to an electric field. Within the particle, the polyurethane molecules at molecular level show a coil structure with cross-linking of the polyether units via the urethane linkages. At the appropri-

ate temperatures and concentrations the Li^+ and/or Zn^{2+} ions, located in the polymer cavities, form coordination bonds with the free electron pairs of the oxygen atoms of the polyethylene glycol groups (see Figure 11). The exposure to an electric field causes the displacement of the Li^+ and/or Zn^{2+} ion within their coordination sphere. This induces a dipole moment leading to the orientation of the particles in the electric field.

6 SUMMARY

Various analytical techniques were applied to characterize the composition of polyurethane based electrorheological fluids. The two examined electrorheological suspensions only differ significantly regarding their added cation (Li^+ and/or Zn^{2+}) to the polyurethane particles. However, both are composed of the same silicone oil and the same polyurethane matrix. Their particle content and the size of the particles are identical as well as the degree of cross-linking of the polyurethane matrix. Therefore the only difference in the cation type defines the principle range of operational temperature. The dependency of the ER effect on temperature is additionally influenced by the polyurethane matrix. A model is derived to describe the occurring effects when polyurethane based ERF are exposed to an electric field. This model ranges from catenation of the particles in the micrometer scale down to molecular dimensions with complexation of the metal cation in the polyurethane matrix.

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