Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Journal of Magnetism and Magnetic Materials 320 (2008) 1322–1327
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Investigating magnetorheological properties of a mixture of two types of carbonyl iron powders suspended in an ionic liquid

Gjergj Dodbiba*, Hyun Seo Park, Katsunori Okaya, Toyohisa Fujita

Department of Geosystem Engineering, Graduate School of Engineering, The University of Tokyo, 7-3-1, Bunkyo-ku, Hongo, Tokyo 113-8656, Japan

Received 24 July 2007; received in revised form 9 October 2007
Available online 6 November 2007

Abstract

In this work, properties of a magnetorheological (MR) fluid, prepared by dispersing a mixture of two types of carbonyl iron powders (CIPs) of different sizes, in an ionic liquid (*N*,*N*-diethyl-*N*-methyl-*N*-(2-methoxyethyl) ammonium tetrafluoroborate) that is stable from 9 °C to ca. 300 °C, have been investigated. At first, the random packing density of the mixture was computed as function of mixing ratio of CIP, in order to find out the tendency of the variation. Next, several mixtures, all having the same weight, were prepared at various mixing ratios and dispersed in the ionic liquid, in order to experimentally find the most suitable mixing ratio of CIP. Then, the magnetic clusters of the synthesized MR fluids were observed by using a digital microscope equipped with two permanent magnets, whereas the MR properties were investigated by using a rotation viscometer equipped with a solenoid coil. The experimental results pointed out that the MR fluid with 60 wt% fraction of large particles exhibited the highest MR response.

Keywords: Carbonyl iron powder; Ionic liquid; MR fluid; Discrete element method (DEM); Random packing density

1. Introduction

Generally speaking, magnetorheological (MR) fluids are dispersions of (1–10 μm) ferrimagnetic or ferromagnetic particles in an organic or aqueous carrier liquid [1]. They must posses certain characteristics including stability over a broad temperature range, stability against settling, chemical stability, etc. [2–5]. Furthermore, MR fluids should exhibit a large field-inducted yield stress with small apparent viscosities in absent of an applied magnetic field [6]. In this frame, the type of the carrier liquid and the effect of size of magnetic particles on the rheology of MR fluid are significant and much attention has been given to this subject [7–14].

In an attempt to improve the performance of MR fluid the authors have investigated the properties of a MR fluid prepared by dispersing a mixture of two types of carbonyl iron powders (CIPs) (i.e. BASF: soft grade CM, and hard grade HQ) in an ionic liquid (i.e. *N*,*N*-diethyl-*N*-methyl-*N*-(2-methoxyethyl) ammonium tetrafluoroborate). The primary reason for selecting an ionic fluid as carrier liquid is that it has a relatively low melting point, is nonvolatile, and does not evaporate [15,20]. Hence, the ionic liquid may be used in high-vacuum systems, eliminating the containment problems.

At first, the random packing density of the mixture was computed as a function of the mixing ratio of CIP, in order to find out the tendency of the variation. In other words, the random packing density of a binary mixture of spherical iron particles was calculated as function of mixing ratio, by using the discrete element method (DEM) [16]. Next, several mixtures of CM (mean diameter, $d_{50} = 7\,\mu m$) and HQ (mean diameter, $d_{50} = 1.1\,\mu m$) iron powders, all having the same weight, were prepared at various mixing ratios and dispersed in the ionic liquid, in order to experimentally find the most suitable mixing ratio of CIP, when preparing a MR fluid. At last, the magnetic clusters of the synthesized MR fluids were observed by using a digital microscope equipped with two permanent magnets, whereas the MR properties were investigated by using a rotation viscometer equipped with a solenoid coil.

*Corresponding author. Tel.: +81 3 5841 7077; fax: +81 3 5841 7075.
E-mail address: dodbiba@geosys.t.u-tokyo.ac.jp (G. Dodbiba).

0304-8853/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmmm.2007.10.031

2. Experimental

2.1. Materials

In this work an ionic liquid, namely *N*,*N*-diethyl-*N*-methyl-*N*-(2-methoxyethyl) ammonium tetrafluoroborate, $C_8H_{20}ONBF_4$ (FW: 233.1), a commercial product of Kanto Chemical, Japan was used as carrier liquid. Fig. 1 shows the structure of $C_8H_{20}ONBF_4$ (specific gravity: 1.17). This type of ionic liquid melts at 9 °C and decomposes at about 300 °C [17–19]. Fig. 2, on the other hand, shows the viscosity of $C_8H_{20}ONBF_4$ as a function of temperature [17].

CIP, used throughout this work, were commercial products of BASF Corporation. Two types of CIPs were selected for investigation: (1) CIP-soft grade CM (hereafter named also as fraction of large Fe particles), mean diameter: $d_{50} = 7\,\mu m$; and (2) CIP-hard grade HQ (hereafter named also as fraction of small Fe particles), mean diameter: $d_{50} = 1.1\,\mu m$. The mean diameter ratio (λ) of large to small particles is ca. $\lambda = 6.4$.

Mixtures of CM and HQ CIPs, dispersed in the ionic liquid, were prepared at a fixed weight of solid fraction ($\Phi = 80.6$ wt%) while varying the weight of large particles. Table 1 tabulates the composition of the MR fluids synthesized for the investigation.

2.2. Measurements

The width of magnetic clusters of the synthesized fluids (see Table 1) was examined by using a digital microscope (Keyence VXH-100), equipped with an 18 million-pixel CCD camera. A set of two permanent magnets were also fixed to the stand of the microscope to create a magnetic field, under which the magnetic clusters were formed and observed.

Moreover, the MR properties of the synthesized fluids have been investigated by using a rotation viscometer. The radius of inner cylinder and the radius of outer cylinder of viscometer were 1.35 and 1.50 cm, respectively. The space between cylinders was filled with MR fluid at a depth of 7.5 cm. The viscometer was also equipped with a solenoid coil to create a magnetic field. All measurements were carried at room temperature.

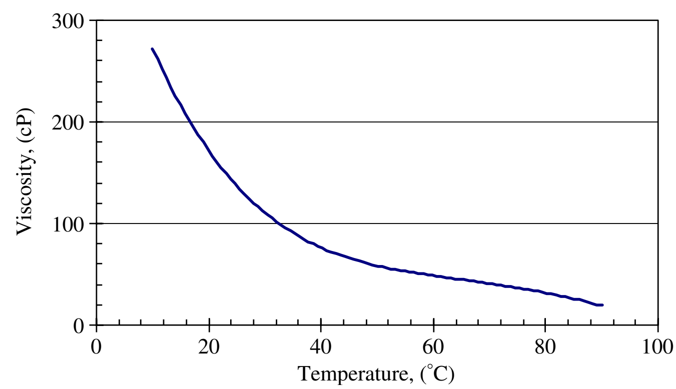

Fig. 2. Viscosity of *N*, *N*-diethyl-*N*-methyl-*N*-(2-methoxyethyl) ammonium tetrafluoroborate ($C_8H_{20}ONBF_4$) as a function of temperature [17].

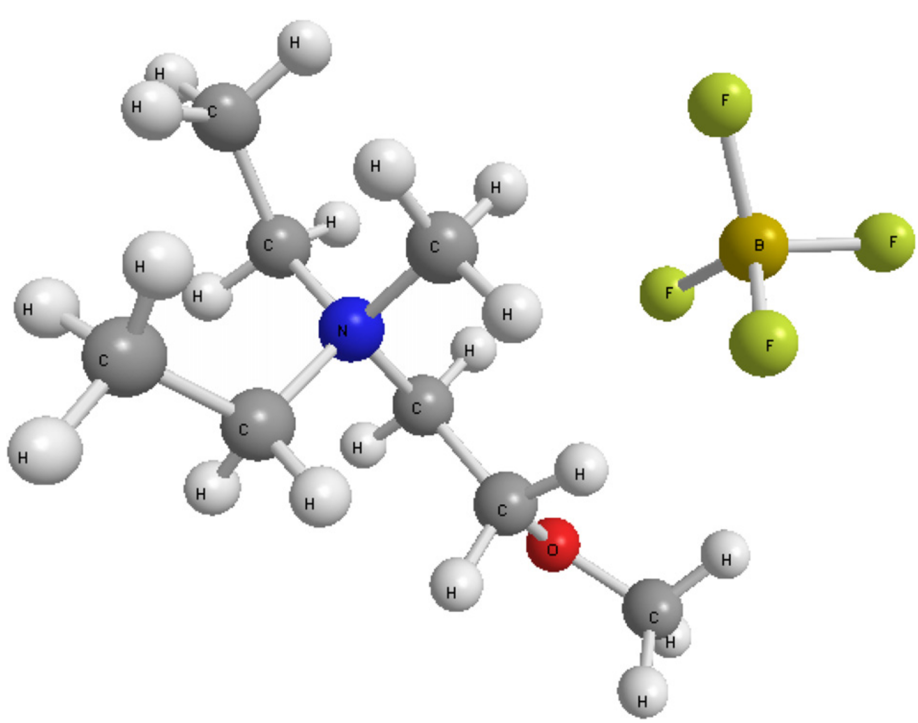

Fig. 1. Structure of *N*, *N*-diethyl-*N*-methyl-*N*-(2-methoxyethyl) ammonium tetrafluoroborate, $C_8H_{20}ONBF_4$.