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Preparation and properties of temperature-sensitive magnetic fluid having $Co_{0.5}Zn_{0.5}Fe_2O_4$ and $Mn_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles

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Abstract

Magnetic properties of $Co_{0.5}Zn_{0.5}Fe_2O_4$ and $Mn_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles and preparation of temperature-sensitive magnetic fluid are discussed in this paper. Ferrofluids having $Co_{0.5}Zn_{0.5}Fe_2O_4$ and $Mn_{0.5}Zn_{0.5}Fe_2O_4$ fine particles were prepared by co-precipitation and by ball milling the precipitated fine particles. Ball milling technique was used for coating of the surfactant rather than size reduction. The final cation contents estimated from the prepared powder samples agree with the initial degree of substitution. The powder samples were characterized by XRD, VSM and Mossbauer studies. The precipitated particles were less than 10 nm size and showed FCC spinel structure. Mossbauer studies confirm the single domain nature of the fine particles. Temperature-sensitive ferrofluid having transformer oil as the carrier liquid was prepared by carrier exchange technique. $Co_{0.5}Zn_{0.5}Fe_2O_4$ particles can be used for the preparation of temperature-sensitive magnetic fluid with relatively large magnetic volume force.

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Keywords: Magnetic fluids; Chemical co-precipitation method; Fine magnetic particles; Thermomagnetic coefficient; Nanoferrites

1. Introduction

In the case of spinel ferrites, the values of magnetization and Curie temperature can be conveniently varied by suitable variation in composition. Among different magnetic materials, Zn-substituted spinel-type ferrites are attractive

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because Zn substitution alters their magnetic parameters in a wide range of values. This allows us to obtain materials exhibiting different thermomagnetic coefficients. Nanoparticles produced by co-precipitation method allow the surface to adsorb ions or surfactants, necessary for the formation of stable colloidal suspension (ferrofluids). For different technological applications, one has to synthesize magnetic fluids with varying physical properties. In order to make use of the magnetically induced convection for thermal dissipation, it is necessary to use ferrofluids with large pyromagnetic coefficient, i.e., fluids with high saturation magnetization and low Curie temperature. The behavior of magnetic colloidal fluids in power transformers has been reported by Segal et al. [1]. Synthesis and characterization of temperature-sensitive magnetic fluids having $Mn_{0.5}Zn_{0.5}Fe_2O_4$ fine particles were reported by Upadhyay et al. [2]. Preparation and properties of Mn–Zn ferrite nanoparticles for aqueous and hydrocarbon-based ferrofluids have been reported by Auzans et al. [3,4]. Thermomagnetic properties of ferrofluids containing chemically co-precipitated Mn–Zn ferrite particles have been reported by Blums et al. [5]. High field magnetization of the colloidal Mn–Zn ferrite has been investigated by Maiorov et al. [6]. Modified synthesis technique for Mn–Zn ferrite with higher magnetization for temperature-sensitive magnetic fluid has been reported by Jeyadevan et al. [7]. Temperature-sensitive magnetic fluid having different Zn-substituted mixed ferrites ($Co_{0.3}Zn_{0.7}Fe_2O_4$) for the study of thermal convection have been reported by Fujita et al. [8]. The radius of the nanoparticle in a magnetic fluid containing $Co_{0.7}Zn_{0.3}Fe_2O_4$ in a diester carrier has been reported by Fannin et al. [9]. In this paper, we report the preparation technique and properties of transformer oil-based temperature sensitive magnetic fluid having $Co_{0.5}Zn_{0.5}Fe_2O_4$ and $Mn_{0.5}Zn_{0.5}Fe_2O_4$ fine particles.

2. Experimental

2.1. Synthesis of fine particles and temperature-sensitive ferrofluid

$Co_{0.5}Zn_{0.5}Fe_2O_4$ and $Mn_{0.5}Zn_{0.5}Fe_2O_4$ fine particles were prepared by the usual chemical co-precipitation method. Mixed aqueous solution of $CoCl_2$, $ZnSO_4$, $FeCl_3$ and $MnCl_2$, $ZnSO_4$, $FeCl_3$ in their respective stoichiometry was precipitated using sodium hydroxide solution. Details of the preparation of fine particles are given in Ref. [10]. Volatile hydrocarbon-based (heptane) ferrofluid was prepared from the precipitated fine particles directly by using oleic acid as the surfactant in the alkaline medium itself. Oleic acid was converted to sodium oleate and was transferred to the reaction vessel. Stirring was continued for nearly 3 h and coating of surfactant was carried out at a temperature of about 80 °C. To coagulate the oleic acid-coated particles, dilute HNO_3 was added. After decantation, the product was washed a number of times with distilled water to remove soluble impurities. After removal of excess water by acetone washing, the coated particles were dispersed in heptane.

Part of the precipitated fine particles (before the addition of surfactant) was collected separately using magnetic separation and washed several times with distilled water. Finally, acetone was used for removing water and the particles were dried at room temperature. The collected particles were ball-milled, using Retsch –PM400, along with the surfactant (oleic acid) and the carrier liquid (heptane). Agate balls (10-mm-diameter) and jars (150 ml) were used. The ball mill was operated at 300 rpm and the ball to weight ratio was maintained as 5:1. Carrier exchange technique was used to prepare transformer oil-based temperature sensitive ferrofluids using the co-precipitated and ball-milled fluid samples.

2.2. Characterization

X-ray characterization of the powder samples was carried out using Rigaku X-ray diffractometer having Cu Kα radiation. Specific magnetization (M_S) of the powder samples at room temperature was measured using a vibrating sample magnetometer (VSM Tamakawa model TM-VSM1230-HHHS). Mossbauer spectra were taken (Wissel Instrument) at room temperature with ^{57}Co source in rhodium matrix, operated in constant acceleration mode. For fitting the data 'Normos' least-squares fitting program was used. Pulse field