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Effect of thermal aging on stability of transformer oil based temperature sensitive magnetic fluids

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ABSTRACT

Synthesizing stable temperature sensitive magnetic fluids with tunable magnetic properties that can be used as coolant in transformers is of great interest, however not exploited commercially due to the lack of its stability at elevated temperatures in bulk quantities. The task is quite challenging as the performance parameters of magnetic fluids are strongly influenced by thermal aging. In this article, we report the effect of thermal aging on colloidal stability and magnetic properties of $Mn_{1-x}Zn_xFe_2O_4$ magnetic fluids prepared in industrial grade transformer oil. As-synthesized magnetic fluids possess good dispersion stability and tunable magnetic properties. Effect of accelerated thermal aging on the dispersion stability and magnetic properties have been evaluated by photon correlation spectroscopy and vibration sample magnetometry, respectively. Magnetic fluids are stable under accelerated aging at elevated temperatures (from 50 °C to 125 °C), which is critical for their efficient performance in high power transformers.

1. Introduction

Magnetic fluids are colloidal dispersion of magnetic nanoparticles in carrier liquid. It combines both the fluidic and magnetic properties in single domain system. They find variety of applications in diverse field of science and technology, which is ranging from space science to nanomedicine [1]. These fluids are used as a 'liquid seal' in hard drives, as dampers in automobiles and aerospace, as drug carriers in magnetically guided drug delivery and as contrast agents in MRI [2–4]. Another promising application of magnetic fluids is to use them as coolant in heat exchangers and in magnetocaloric energy conversion devices like high power transformers [5]. Heat transfer in oil immersed transformers can be improved significantly if convectional mineral oil is replaced with temperature sensitive magnetic fluid in transformers [6]. In temperature sensitive magnetic fluids; the magnetization of fluid strongly depends on fluid temperature. When exposed to temperature gradient, they exhibits magnetic convection in addition to natural convection caused by the density gradient. This additional drag force enhances the cooling efficiency of the fluid and thus improves their performance in transformers.

In order to use magnetic fluids in heat exchange devices, they should possess large thermomagnetic coefficient and suitable Curie temperature, which should be matching with the operating temperature of device. Temperature sensitive magnetic fluids suitable for cooling applications in high power transformers should have Curie temperature between 70 °C and 300 °C [7]. Most substituted ferrites used in the preparation of magnetic fluids tend to have Curie temperatures that are too high for practical use in transformers. Curie temperature of mixed metal ferrites lie between 100 °C and 200 °C. Amongst them Mn-Zn ferrite nanoparticles are well suited for thermo-magnetic coolants, because of their moderate saturation magnetization and tunable Curie temperature [8,9].

Magnetic nanoparticles dispersed in transformer oil should be able to withstand the device's operating temperature without any loss in their dispersity [6]. One of the important parameter that effects the stability of the magnetic fluids is the size of nanoparticles and its distribution. Small size of nanoparticles and narrow size distribution is essential to prepare stable magnetic fluids [8]. Arulmurugan et al. have reported synthesis of $Mn_{1-x}Zn_xFe_2O_4$ (x = 0.1–0.5) nanoparticles with Curie temperatures from 160 °C to 360 °C. They have observed that Curie temperature of $Mn_{1-x}Zn_xFe_2O_4$ nanoparticles decreases with increasing Zn content [10]. Giri et al. and Mohapatra et al. have reported surface controlled synthesis of MFe_2O_4 (M = Mn, Fe, Co, Ni and Zn) nanoparticles and studied effect of surface ligands on the magnetic properties of MFe_2O_4 nanoparticles [11–13]. Desai et al. have reported synthesis of $Mn_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles with tunable Curie temperature and saturation magnetization using

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hydrothermal method [14]. Particle size was controlled between 5 and 13 nm by varying pH and incubation time of the reaction. Magnetic fluids prepared with these nanoparticles have large polydispersity and poor colloidal stability. Colloidal stability of magnetic fluids prepared from maghemite nanoparticles grafted with oleic, dodecanoic and decanoic acid was studied by Sartoratto et al. [15]. All magnetic fluids have good colloidal stabilities when stored at 25 °C. At elevated temperature (90 °C), only the oleic acid-grafted magnetic fluid is stable. Parekh et al. [16] has also reported the magnetocaloric properties of $Mn_{0.5}Zn_{0.5}Fe_2O_4$, $Fe_{0.5}Zn_{0.5}Fe_2O_4$, and $Fe_{0.3}Zn_{0.7}Fe_2O_4$ fluids.

Table 1
Sample code and composition of temperature sensitive magnetic fluids.

Sample code	Composition of magnetic nanoparticles
MZ0	$MnFe_2O_4$
MZ2	$Mn_{0.8}Zn_{0.2}Fe_2O_4$
MZ4	$Mn_{0.6}Zn_{0.4}Fe_2O_4$
MZ6	$Mn_{0.4}Zn_{0.6}Fe_2O_4$
MZ8	$Mn_{0.2}Zn_{0.8}Fe_2O_4$

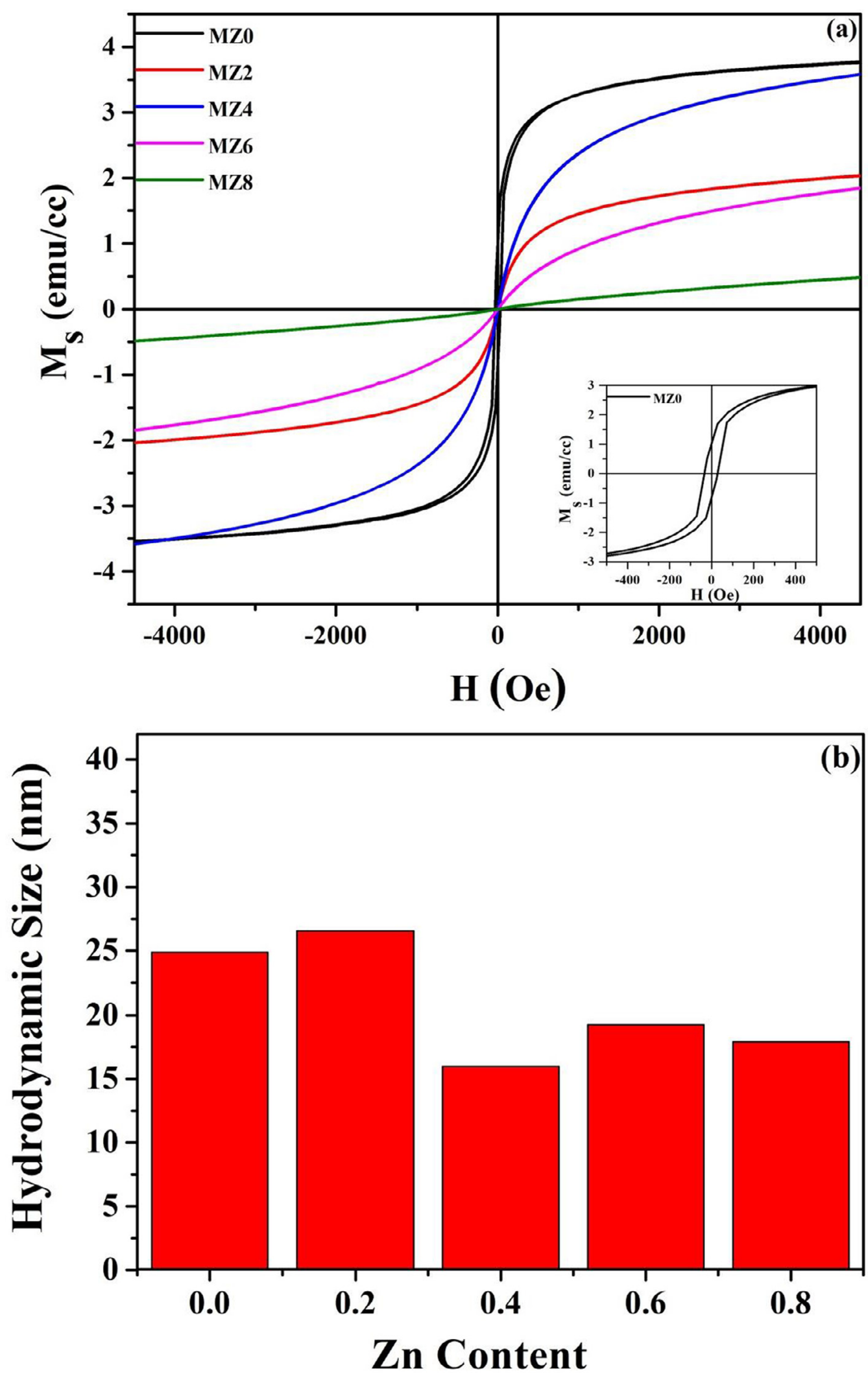

Fig. 1. (a) Magnetization and (b) hydrodynamic particle size of as-synthesized MZ fluids measured at room temperature.