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Evaluation of colloidal stability of maghemite-based magnetic fluids for transformer application

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Abstract: The colloidal stability of magnetic fluids (volume fractions in the range 0.2-0.005%) consisting of oleic acid-coated maghemite nanoparticles (5-9 nm) dispersed in insulating naphtenic oil was investigated at room temperature and upon heating in the range 90-185°C (accelerated aging experiment). Under heating, all diluted MF samples lost stability, except the MF samples prepared by dispersing oleic acid-coated maghemite particles in insulating vegetable oil. Acidity index, water content, dielectric strength, resistivity and magnetic susceptibility of diluted magnetic fluid samples were evaluated by standard methods before and after heating at 90°C for 300 h in the presence of typical materials used to build the internal parts of a commercial power transformer.

Development of oil-based magnetic fluid (MF) samples for use in high voltage transformers technology requires highly-stable MFs, displaying specific electrical properties and able to operate at temperatures above 100°C. The stability of organic-based MF samples can be achieved from balancing Van der Waals, magnetic dipole and steric interactions, the latter due to the presence of long chain hydrocarbon molecules attached onto the surface of the suspended nanoparticle. Once this particular application requires low nanoparticle's volume fraction (around 0.01%), in order to guarantee high electrical resistivity [1], it is essential to evaluate the MF colloidal stability under this condition. Chemical and physical characteristics such as acidity index, water content, stability upon oxidation, presence of sulfates and chorides, density, viscosity, dielectric strength, resistivity and magnetic susceptibility are important as well. In this study, the colloidal stability of magnetic fluids (volume fractions in the range 0.2-0.005%) consisting of oleic acid-coated maghemite nanoparticles (5-9 nm) dispersed in insulating naphtenic oil was investigated at room temperature and upon heating in the range 90-185°C (accelerated aging experiment). Chemical and physical properties of diluted magnetic fluid samples were evaluated by standard methods before and after heating at 90°C for 300 h in the presence of typical materials used to build the internal parts of a commercial power transformer (kraft paper, copper, and steel).

Table 1: Chemical and electrical properties of the naphtenic oil-based MF sample (0.01% volume fraction) before (MF) and after thermal treatment (HMF) in comparison with pure oil.

Material	Water content (ppm)	Acidity Index (mgKOH/g)	Dieletric Strength (kV/0.1")	Resistivity ($x10^{10}$ Ω)
Naphtenic oil	23	0.00955	53	85
MF	35	0.134	53	2.3
HMF	26	0.143	56	2.9

Colloidal stability was evaluated by visual inspection of the MF samples and by dynamic light scattering, providing the nanoparticle' hydrodinamic radius. Under room temperature storage magnetic fluids with higher volume fraction (0.2 to 0.05%) were very much stable (more than 3 years), whereas samples with very low volume fraction (0.005%) are unstable, loosing stability within months or days, depending on the water content. Under heating, all diluted MF samples lost stability, except the MF samples prepared by dispersing oleic acid-coated maghemite particles in insulating vegetable oil.

Reference

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