Experimental report

18/08/2017

Proposal: **5-32-826**

Council: 4/2016

Title: Investigation of structural and magnetic changes in transformer oil-based ferrofluids induced by electric field

Research area: Materials

This proposal is a new proposal

Main proposer: **Michal RAJNAK**

Experimental team: Michal RAJNAK

Local contacts: Dirk HONECKER

Samples: ferrofluid (transformer oil, magnetite nanoparticles, oleic acid)

Instrument	Requested days	Allocated days	From	To
D33	4	3	16/09/2016	19/09/2016

Abstract:

Dispersion of superparamagnetic nanoparticles in transformer oils constitute an extraordinary cooling and electrical insulating medium (ferrofluid) with higher breakdown voltage than those for pure transformer oils. The peculiar dielectric behavior and breakdown mechanism is still not clear. We propose to study a ferrofluid magnetization changes in relation to the particle structural reorganization brought on by an external electric field. In the proposed study it is intended to verify, if the geometrical alignment of superparamagnetic nanoparticles induced by electric forces (polarization and dielectrophoresis) also results in alignment of their magnetic moments. By the proposed experiment we would find out, if the electric field can bring superparamagnetic nanoparticles close enough in order to stop the superparamagnetic moment fluctuations and give rise to magnetic dipole-dipole interactions, forming so magnetic structures. The knowledge about such structures can shed light on the breakdown mechanism, while general relation between the electric and magnetic properties of magnetic nanoparticles can open a new avenue of ferrofluid research.

Experimental report

Investigation of structural and magnetic changes in transformer oil-based ferrofluids induced by electric field

M. Rajnak[1], M. Timko[1], P. Kopcansky[1], A. Feoktystov[2]
[1]Institute of experimental physics SAS, Kosice, Slovakia
[2]Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ), Forschungszentrum Jülich GmbH, Garching, Germany

Scientific background

Transformer oils (TO) constitute a major part of the electrical insulation system in many types of electrical equipment. Besides the electrical insulation, they provide effective heat transfer, acting as a coolant. To increase the lifetime and reliability of electrical equipment it is necessary to decrease its operation temperature. For that purpose, researchers look for additives enhancing the TO's thermal properties and retaining their excellent insulating characteristics. One of the promising additives are superparamagnetic nanoparticles (SNP) whose stable dispersions in TO constitute ferrofluids with a potential application in electrical engineering. From dielectric point of view, the presence of SNP in TO increases their electric permittivity, and can even increase their dielectric breakdown field strength. This paradoxical finding is still not fully understood. A theoretical modeling has indicated that SNP in TO can act as free charge scavengers which slow down the streamer velocity leading to dielectric breakdown. It is therefore intuitive that knowledge about interactions and structural behavior of SNP in electric fields are of fundamental importance in the comprehension of the peculiar breakdown mechanism. Recently, SNP aggregation in electric fields was deduced from dielectric measurements and formation of anisotropic structures was proved by small angle neutron scattering. Thus, the aim of the proposed experiment was to investigate the relation of the electric field induced structural changes in a ferrofluid in regard to their magnetic properties. In the experiment, SANSPOL intensities $I^{+}(q)$, $I^{-}(q)$ were measured depending on the external electric field.

Experimental results

By means of this experiment we studied the effect of external electric field on structural behavior of magnetite nanoparticles dispersed in transformer oil (ferrofluid). The ferrofluid sample was placed in a standard quartz cuvette (Hellma, 1 mm thick). There, it was exposed to the external electric field of various intensities, which was generated between two tubular electrodes immersed in the sample. Once the field was applied to the sample, SANSPOL curves were measured following the proposed experimental protocol. Besides the electric field effect, we have studied the effect of magnetic field acting both, alone and simultaneously with the external electric field.

In Fig. 1, one can see that the electric voltage acting on the ferrofluid causes a remarkable increase in scattering intensity at small q range. This increase is proportional to the strength of the field. The increase in the intensity originates from the presence of larger aggregates in the sample which were induced by the applied electric field. In the static electric field the particles are polarized and due to the high dielectric contrast between the transformer oil and magnetite, the induced dipoles are strong enough to activate the attractive interaction. Looking at the scattering curve, one can distinguish two regions at q values below and above 0.01. Whereas the curve above q = 0.01 is formed mainly by the scatterers presented also in the original sample (in the absence of electric field), the shape of the curve below this value is associated with the formation of aggregates. From this q value it is possible to estimate the minimum size of the aggregates which is about 64 nm. However, the curve is missing information about the final size and shape of the aggregates which would appear at even smaller q values. We therefore look at the small q slope as at a tail resembling the Porod's law and we expect that the curve would reach saturation at smaller q range (Guinier).

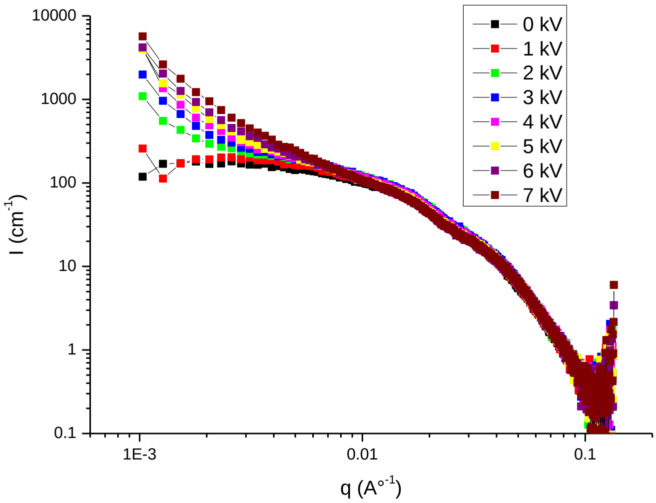

Fig. 1 SANS profiles measured on the ferrofluid sample exposed to various electric voltages.

Fig. 2 shows that there is no remarkable difference between the scattering intensity of up and down neutron spins, so pointing out the absence of any magnetic structure in the created aggregates. The identical SANSPOL curves are observed for both cases, in the absence and presence of the electric field.

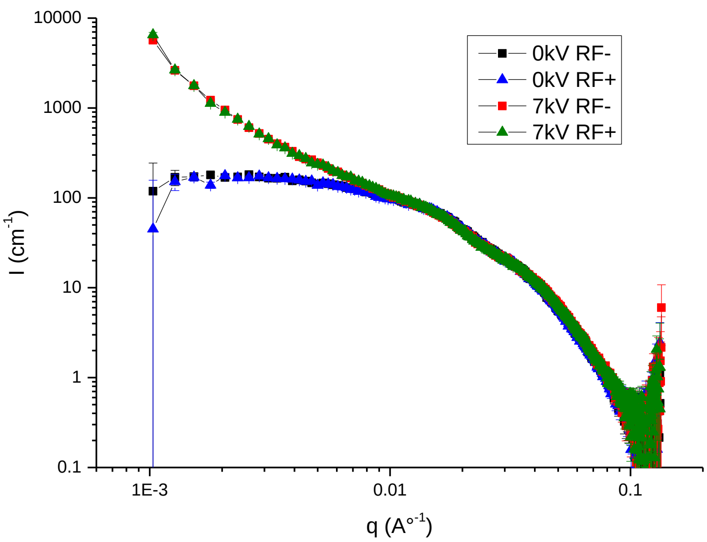

Fig. 2 SANSPOL curves measured on the ferrofluid sample under zero and 7 kV voltage.

A noticeable difference in the SANSPOL curves has been detected in the case, when the sample is simultaneously exposed to both, electric and magnetic field. In magnetic field only, the SANSPOL curves indicate the well-known chain like anisotropy in the magnetic field induced aggregates (Fig. 3). The most pronounced difference in the SANSPOL curves is seen in the case when both, magnetic (425 mT) and electric (7 kV/cm) fields act on the ferrofluid sample. As the magnetic field was applied firstly on the sample and subsequently the electric voltage was switched on, one can assume that the electric field enhanced the magnetic anisotropy in the formed aggregates. This effect will be verified by magnetic susceptibility measurements dependent on the voltage acting on the studied ferrofluid.

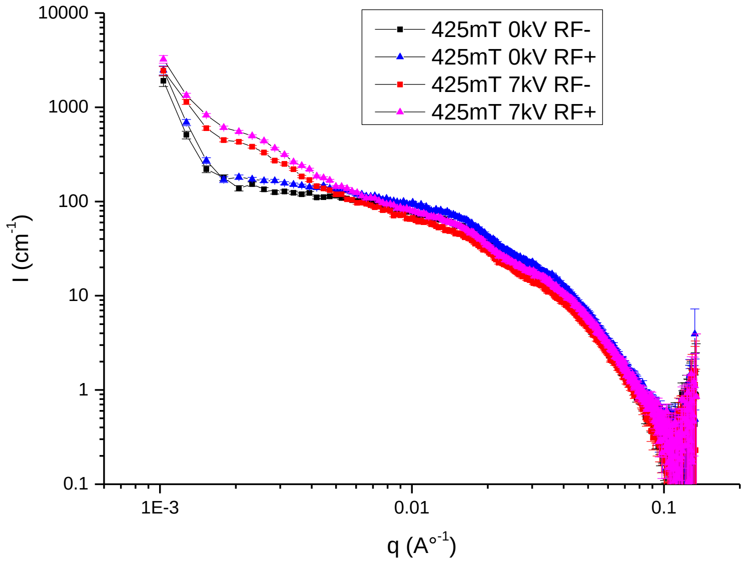

Fig. 3 Simultaneous effect of electric and magnetic field on the SANSPOL curves.