

# Nanofluid Based on New Generation Transformer Oil: Synthesis and Flow Properties

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In this paper, we focused on synthesis, basic characterization and flow properties of nanofluids in which a new generation transformer oil as carried liquid was used. These oils are known as GTL based transformer oils due to Gas-To-Liquids technology developed for producing iso-paraffinic hydrocarbon that were derived initially from natural gas. GTL oils are purer, chemically stable and have significantly higher lightning impulse breakdown voltage than normally used mineral oils on the paraffinic and the naphthenic base. Prepared nanofluids (NFs) contain ferrimagnetic nanoparticles of magnetite (MNPs) with a spinell structure. By employing chemical co-precipitation technique MNPs were synthesized. The mass concentration of the suspended MNPs in NFs was changed from 0.2 to 13.3%, and the M-H loops revealed the superparamagnetic behavior of NFs recorded at room temperature. The mass fraction and average particle size of MNPs were obtained from vibrating-sample magnetometer measurements. In turn, rheological characterization of NFs was performed by using a rotational rheometer in the temperature range from 293 to 353 K in dependence of the shear rate. The experimental results show that the crucial properties of GLT oil are positively reflected in the properties of the prepared NFs.

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## 1. Introduction

Nowadays we often encounter the term nanomaterials, a wide range of which appears on the market of various products. The main ingredients are nanoparticles of different origins, in particular, either dispersed in the liquid medium or a gel, which are indicated by the term nanofluids (NFs). Due to their unique properties they found use in a number of scientific disciplines. In the field of electrotechnics and power engineering, these composite materials represent a way of reducing the dielectric and thermal losses of various devices and are a perspective cooling and insulating medium. However, current technologies have reached their limits due to the inadequate intrinsic thermal conductivity of conventional cooling liquids [1–3]. Using the new generation insulating oil manufactured by the Gas-To-Liquids technology (GTL) is one of the possible approaches to improve their properties. Compared with conventional mineral oils, the designed GTL oil offers a high degree of compositional and performance consistency, high purity, excellent resistance to degradation, it is essentially sulphur free and has significantly higher lightning impulse breakdown voltage [4]. Additionally, the presence of foreign particles in these liquid insulators can further improve their properties, especially when using external fields. These nanoparticles can be metallic, non-metallic, oxide, carbide, ceramics,

carbonic, hybrid nanoparticles. The mixing of nanoparticles with the base fluid may alter the thermophysical properties of fluids as the nanoparticles possess higher thermal conductivity than the base fluids. However, various experiments have shown that the increase of thermal conductivity might be offset by an increase of viscosity. The rheological behavior of NFs depends on various factors such as nanoparticle shape, size, concentration, used surfactants and shear rate range, and also it can be influenced by external applied magnetic or electric fields [1–6].

## 2. Materials and methods

For preparing magnetite nanoparticles (MNPs) iron (II) sulfate heptahydrate ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ), iron (III) chloride hexahydrate ( $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ ) and ammonium hydroxide solution ( $\text{NH}_4\text{OH}$ ) were used. Oleic acid ( $\text{C}_{17}\text{H}_{33}\text{COOH}$ ) as a surfactant was used for stabilization of the synthesized MNPs. All raw materials were of analytical reagent grade and were used without any further purification. GTL transformer oil (Shell Diala S4 ZX-I) was used as the carried liquid [4]. The preparation of basic sample NF consisted of two main steps. At the beginning, nanoparticles of magnetite were obtained by the chemical precipitation of ferrous and ferric salts in molar rate 1:2 in alkali medium at the temperature 353 K. In the following step, MNPs were sterically stabilized and coated by single layer of oleic acid at the temperature range 353–355 K. The coated nanoparticles with hydrophobicity character were dispersed in carrier liquid of nonpolar character to get a stable suspension without

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any phase separation and sedimentation [7]. The samples named by NF1-NF6 with different particle mass fractions  $\phi_M$  were obtained by diluting the original NF sample. The exact concentration and magnetic properties of NFs were determined from the analysis of magnetization curves recorded by using vibrating-sample magnetometer (VSM) from Cryogenic Ltd. Rheological characterization of NFs was performed in a Physica Anton Paar GmbH MCR-502 rheometer using two parallel plates configuration with Peltier temperature control. The gap between plates was 0.328 mm, the diameter of plates was 16 mm. The temperature dependence of the viscosity was measured at the shear rate  $50 \text{ s}^{-1}$  in the temperature range from 293 to 353 K.

3. Results and discussion

As one can see in Fig. 1, the mass magnetization curves of studied NFs show zero coercivity and remanence at 298 K. For better clarity only the magnetization loops for the primary sampled NF were displayed at 298 K and at 1.8 K. The hysteresis (inset in Fig. 1) revealed at the low temperature and the high temperature paramagnetic nature of the depicted curve confirming the blocked state and the superparamagnetism of the MNPs, respectively [8].

The saturation magnetization of individual sample increases with increasing amount of MNPs in NFs (Fig. 2). The magnetic mass fraction was estimated as a ratio of the NF mass magnetization of saturation (12.789 emu/g) to the magnetization of saturation of magnetite (96 emu/g) [9], giving the value of about 13.3%. The mean particle diameter was 10.3 nm. It was determined by fitting the magnetization curve using the Langevin function which very closely describes the magnetic behavior of the same size MNPs. The obtained values of saturation magnetization and other determined characteristics of studied NFs are summarized in Table I.

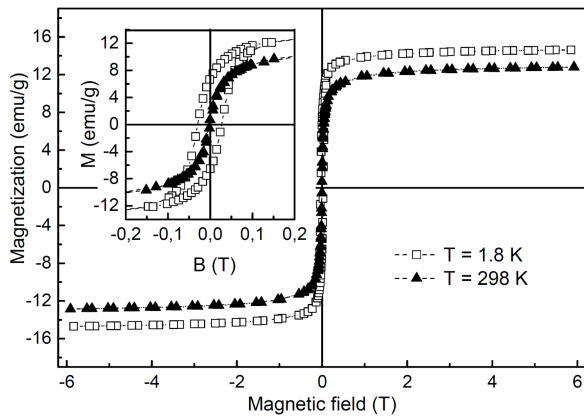


Fig. 1. Magnetization loops of the magnetic fluid NF at temperature of 1.8 K and 298 K.

TABLE I

The properties of studied samples: saturation magnetization  $M_S$ , magnetic mass fraction  $\phi_M$ , density  $\rho$ , relative viscosity  $\eta/\eta_0$  (where  $\eta_0$  is the viscosity of GTL oil), and activation energy  $E_a$ .

Sample	$M_S$ [emu/g]	$\phi_M$ [%]	$\rho$ [g/cm <sup>3</sup> ]	$\eta/\eta_0$	$E_a$ [kJ/mol]
NF	12.789	13.3	0.965	1.473	19.989
NF1	8.830	9.3	0.908	1.347	20.391
NF2	4.800	5.1	0.860	1.193	20.683
NF3	2.390	2.5	0.834	1.163	19.619
NF4	1.440	1.5	0.823	1.120	20.347
NF5	0.420	0.4	0.813	1.098	20.066
NF6	0.160	0.2	0.810	1.038	20.496

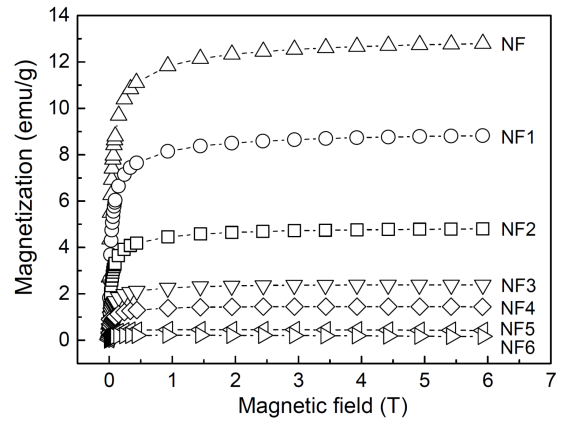


Fig. 2. The first quadrant of magnetization curves measured at room temperature for all studied samples.

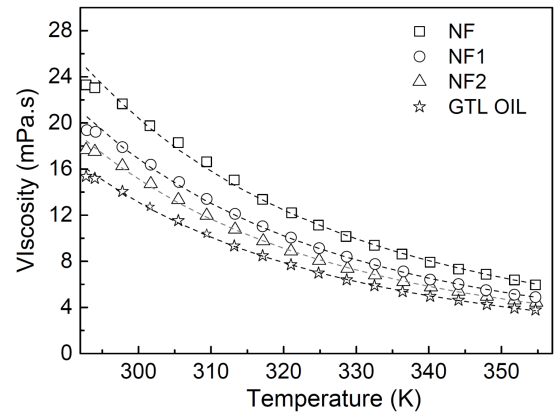


Fig. 3. The temperature dependence of the viscosity at the shear rate  $50 \text{ s}^{-1}$  for NF, NF1, NF2 and GTL oil. The dashed lines represent Arrhenius fit to experimental points.

As it was shown already for other carrier liquid and NFs [10, 11] that all samples and their carrier liquids appear to be Newtonian since their viscosities do not depend on the shear rate. The values of NFs magnetization, the viscosity increase with increasing MNPs content in

the samples. The temperature dependencies of the viscosity at constant shear rate  $\dot{\gamma} = 50 \text{ s}^{-1}$  for selected NFs are illustrated in Fig. 3. For all samples and GTL oil the increase of temperature causes the decrease of their viscosities. The obtained experimental data were fitted with the Arrhenius type formula

$$\eta = \eta_{\text{ref}} \exp\left(\frac{E_a}{RT} - \frac{E_a}{RT_{\text{ref}}}\right),$$

where  $R = 8.314 \text{ J}/(\text{mol K})$  is the universal gas constant,  $E_a$  is the viscous flow activation energy,  $T_{\text{ref}}$  is the reference temperature 293.15 K, and  $\eta_{\text{ref}}$  is the sample viscosity at  $T_{\text{ref}}$ .

#### 4. Conclusions

The goal of this work was to synthesize and characterize novel insulation fluids as a perspective heat transfer nanofluid for devices used in electroenergetics. We focused on liquids containing magnetic nanoparticles  $\text{Fe}_3\text{O}_4$  dispersed in a liquid iso-paraffinic hydrocarbons derived initially from natural gas. We observed a decrease of the viscosity of all samples with increasing the temperature. It is due to the growing Brownian motion of their constituent molecules. Activation energy  $E_a$  needed by the molecules to be set in motion against the frictional forces of the neighboring molecules varies within about 5%. We suppose that in this type of samples and for the used measurement conditions the variable amount of MNPs is not so significant to manifest itself in the determined  $E_a$ . We can assume that the prepared new NF is a stable nanofluid whose preliminary observed characteristics are a promising prerequisite for future research and subsequent use as a coolant.

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