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EXPERIMENTAL INVESTIGATION OF THE THERMAL CONDUCTIVITY AND VISCOSITY OF INSULATING OIL BASED DIAMOND-NICKEL HYBRID NANOFLUIDS

Letícia Raquel de Oliveira
David Fernando Marcucci Pico
Enio Pedone Bandarra Filho
Mechanical Engineering School, Federal University of Uberlandia, Av. João Naves de Ávila, 2121, Uberlandia-MG, Brazil
leticia.raquel@ufu.br
dmarcucci@ufu.br
bandarra@ufu.br

Abstract. *Due to the effect of the nanoparticles on the thermo-physical properties of the base fluid, a kind of hybrid diamond-nickel (Di-Ni) nanoparticle was dispersed in insulating mineral oil in order to produce nanofluids at three different concentrations, up to 0.05 vol%. The sedimentation test was conducted and the nanofluids remained stable for approximately one week; after that period, a gradual sedimentation was observed with the time. Two important thermo-physical properties such as the thermal conductivity and the viscosity were measured under the same conditions, and the experimental results showed that the thermal conductivity of Di-Ni nanofluids increased with the volumetric concentration and temperature. The breakdown voltage, another important property of insulating oils, was also evaluated. Adding hybrid Di-Ni nanoparticles to the insulating mineral oil is helpful to enhance the heat transfer, due to the slightly higher thermal conductivity.*

Keywords: *nanofluids, hybrid, insulating mineral oil, breakdown voltage.*

1. INTRODUCTION

In the last two decades, many researches have focused on the increase of the thermal conductivity of fluid refrigerants with the addition of nanoparticles. As a result, it was obtained a colloidal dispersion called nanofluid. The first researcher to mention this new class of fluid was Choi in 1995.

Recently, studies are being performed concerning the increase of the breakdown voltage by adding nanoparticles to mineral oils used in electrical transformers. The first researcher to add nanoparticles to the transformer mineral oil was Segal et al., (1998).

The main properties of the insulation mineral oil are the breakdown voltage, thermal conductivity and dynamic viscosity. Botha et al., (2011) affirmed that some of the properties, which make transformer oil unique, compared to other oils and suitable as a heat management fluid are the high stability at high temperatures, and the excellent electrical insulating properties. According to Fontes et al., (2015), research has emerged aiming to increase the breakdown voltage of the electrical transformer oil, improving its insulating properties through the dispersion of nanoparticles. Du et al., (2015) added TiO_2 nanoparticles in transformer oil to produce semiconductor nanofluids, aiming to enhance the insulating characteristics. As a result, they have verified that the breakdown voltage of the semiconductor nanofluid with 0.075% concentration in volume of nanoparticles was 1.2 times higher than the pure oil, and that the partial discharge resistance was also improved. Aberoumand et al., (2016) studied Ag/oil the thermal conductivity of nanofluids experimentally. They observed enhancements up to 35% for thermal conductivity. The experiments conducted by Segal et al., (1998) analysed the properties of ferrofluids (mineral oil nanofluids with iron oxide nanoparticles). The viscosity of the ferrofluids was evaluated at different temperatures and did not show significant differences compared with the pure mineral oil.

However, other research has shown opposite results, showing a reduction of the breakdown voltage of the insulating oil when nanoparticles were dispersed. Fontes et al., (2015) obtained a drastic reduction in the breakdown voltage for nanofluids containing carbon nanotubes (MWCNT) and diamond nanoparticles. Conversely, the thermal conductivity of the base fluid was improved up to 25% by the dispersion of the nanoparticles (MWCNT). Botha et al., (2011) also found controversial results to increase the breakdown voltage of their nanofluids. These authors produced silver nanofluids in mineral oil and silver-silica hybrid nanoparticles. They obtained 60.7% reduction in breakdown voltage.

Due to the importance of these electrical appliances, both in industry and in everyday life, it is noticed the large number of studies to understand the mechanisms of heat exchange and properties of nanofluids based on insulating mineral oils. Therefore, the objective of this experimental study was concerned with preparing nanofluids dispersing diamond-nikel (Di-Ni) hybrid nanoparticles in mineral oil (MO), as well as evaluating the breakdown voltage, the thermal characteristics and the rheological properties of pure oil and nanofluids. No kind of surfactant or dispersing agents were used, because they could affect the thermal performance and rheology of nanofluid. Thermal conductivity and viscosity of Di-Ni/MO based nanofluids were measured at different temperatures ranging from 20 to 50°C and low solid volume fractions (0.005% to 0.05%). The results were examined, analyzed and discussed, taking into account the effects of volumetric fraction and temperature.

2. EXPERIMENTAL PROCEDURE

The diamond-Ni (Di-Ni) nanocomposite was synthesized using the chemical method of ethylene glycol (EG) reported by Sundar et al., (2014). The pristine diamond (Di) was obtained from Nanostructured & Amorphous Materials Inc., with nominal purity <97%. The dispersion of Di-Ni nanoparticles in insulating mineral oil was performed using an ultrasound Sonic-Mill (output 1790 W, 20 kHz) as homogenizer, during 30 minutes and with 45% of the amplitude. The Fig.1 shows the ultrasound used.

Figure 1. Ultrasound Sonic-Mill used for synthesis of the nanofluids.

The volumetric concentrations of nanofluids were 0.005%, 0.010% and 0.050%. The solid volume fraction (φ) was obtained using the Eq. (1).

$$\varphi = \frac{\left(\frac{m}{\rho}\right)_{np}}{\left(\frac{m}{\rho}\right)_{np} + \left(\frac{m}{\rho}\right)_{bf}} \tag{1}$$

In which φ is the volume fraction of nanoparticles (%), ρ_{np} denotes the density of TiO_2 nanoparticles, ρ_{bf} is the density of the base fluid and *m* is the mass of base fluid and nanoparticles used.

The thermal conductivity has been measured using a transient hot bridge from Linseis, model THB-1. The probe was immersed in the samples and the measurement was performed by the computer automatically, being carried out 10 measurements for each concentration, varying the temperature from 20°C to 50°C with a thermostatic bath. The measurement uncertainty of the equipment is ± 2%, as specified by the manufacturer and the deviation between each measurement was 2.4%. The dynamic viscosity has been measured in a rotational viscometer, model SVM 3000 from Anton Paar manufacturer, which has a cylindrical geometry. The temperature was controlled and the measurements were performed ranging from 20°C to 50 °C. The measurement uncertainty of the equipment is ± 0.35%, as specified by the manufacturer. The breakdown voltage measurements have been performed in a breakdown voltage equipment manufactured by Triel, model 3E. Fig. 2 shows (a) the experimental apparatus for measuring the thermal conductivity and (b) the viscometer used. Fig.3 shows (a) breakdown voltage measurer (b) vessel with oil and nanofluid.

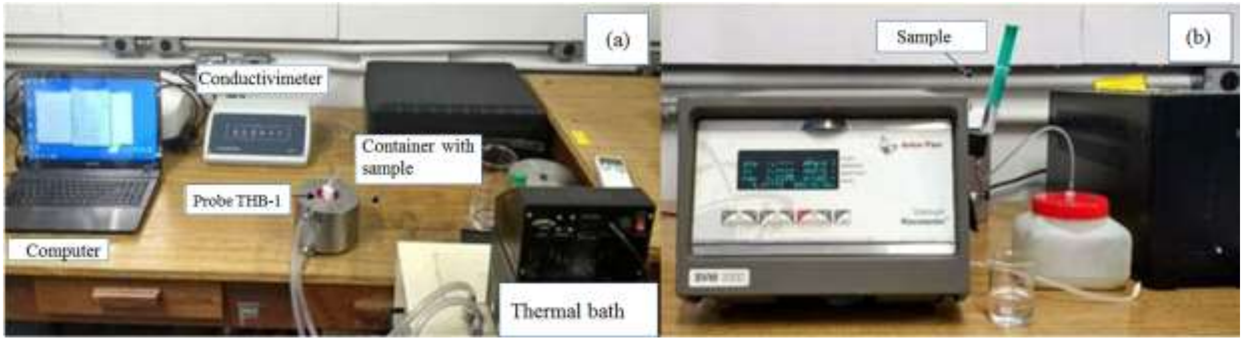

Figure 2. (a) Photo of the experimental apparatus for measuring thermal conductivity, (b) photo of the SVM 3000 viscometer.

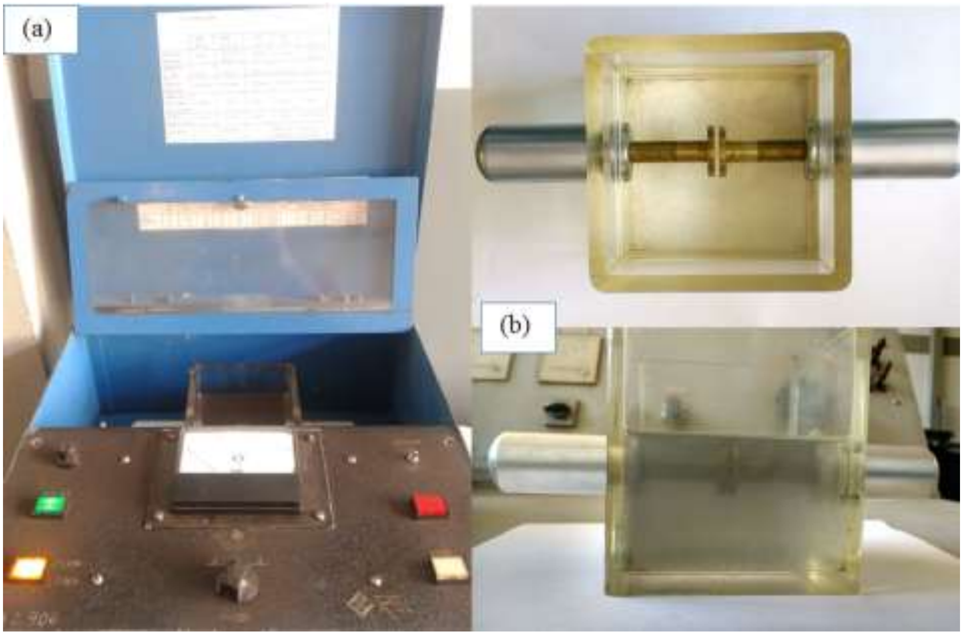

Figure 3. (a) Breakdown voltage measurer (b) vessel with oil and nanofluid, respectively.

3. RESULTS AND DISCUSSION

Fig. 4 shows the SEM image of Di-Ni and EDX hybrid nanoparticles indicating the mass percentage of nickel present in the sample, which confirms the formation of the hybrid nanocomposite.

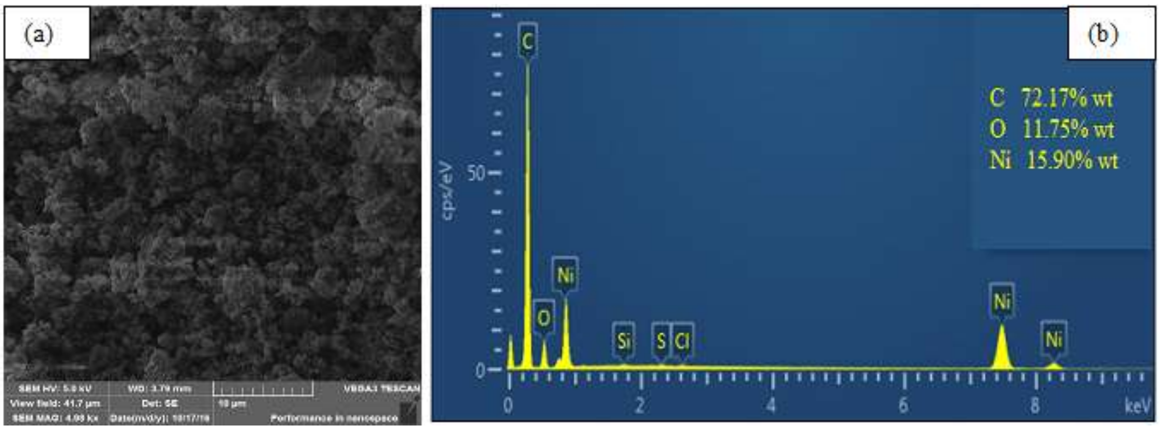

Figure 4. (a) SEM imagem Di-Ni and (b) EDX nanoparticles.

Based on Fig. 5(a), the authors found positive results with the addition of various types of nanoparticles in mineral oil, and these results were consistent with those indicated by Segal et al., (1998), which indicated that dispersing magnetic nanoparticles in oil was not harmful. Besides, nanoparticles increased the dielectric strength. However, in the Fig. 5(b) Fontes et al., (2014) found a reduction of the breakdown voltage with the addition of diamond nanoparticles. They also observed that with the increase of the nanoparticle concentration, the reduction was more pronounced in relation to pure oil.

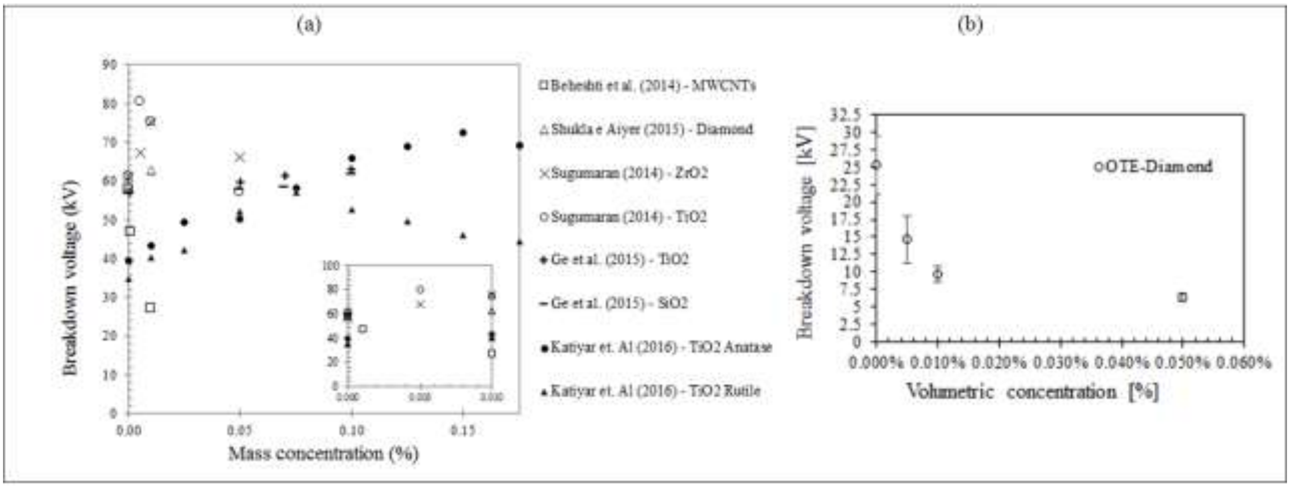

Figure 5. Breakdown voltage of nanofluids (a) several authors and (b) Fontes et al., (2014) results.

The results for the present work were according to those of Fontes et al., (2014), being obtained a reduction of the breakdown voltage with the increase of the volumetric concentration of nanoparticles. The Fig. 6 shows the results obtained for the voltage breakdown for the nanofluids and pure mineral oil. The breakdown voltage deviations found between nanofluids and pure oil may have occurred due to the presence of water, which is one of the main factors that contribute to the reduction of breakdown voltage. Other factors such as oil degradation by oxidation and formation of by-products and higher temperatures may also contribute to this reduction. Nevertheless, the addition of small volume fraction of the mineral insulating oil has been recommended by Dhar et al., (2015) to increase the breakdown voltage of mineral oils. Experimental results from Chiesa and Das (2009) and Hwang et al., (2010) also confirm these results.

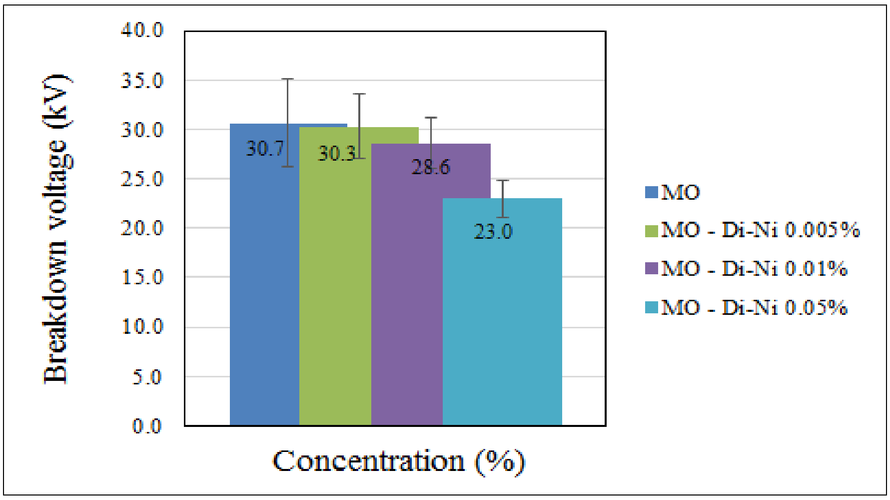

Figure 6. Breakdown voltage of Di-Ni/mineral oil nanofluids.

The thermal conductivity of Di-Ni nanofluids was measured, in order to evaluate its possible enhancement as a function of particles loading and temperature. Mean values of thermal conductivity measured in this study are shown in Fig. 7(a) for different temperatures as a function of volume fraction.

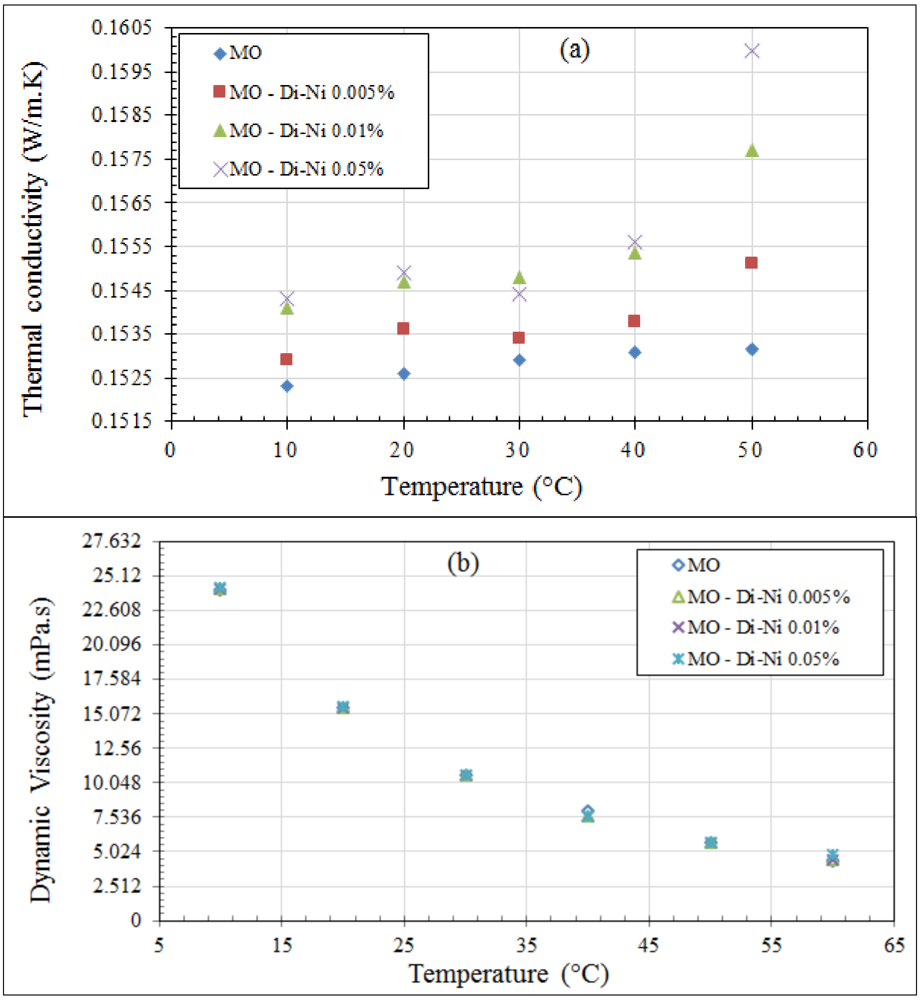

Figure 7. (a) Thermal conductivity and (b) viscosity of Di-Ni/mineral oil nanofluids.

It was observed that for the concentration of 0.05 vol% the highest value obtained for the thermal conductivity was achieved. Additionally, the thermal conductivity increased with the concentration, as well as grows with the temperature. In general, significant enhancement was observed in the thermal conductivity of nanofluids compared to pure oil, 0.32 up to 4.47%.

Fig. 7(b) shows the values of viscosity for different temperatures of the nanofluids. The addition of nanoparticles changes the viscosity of the fluid making it larger with the concentration. The results show that the viscosity decreased with the temperature. It is noteworthy that the addition of Di-Ni nanoparticles did not significantly affect the viscosity of nanofluids compared to pure insulating oil. The highest deviation was 0.98% for 0.005 vol% at 10°C, reinforcing that the addition of the Di-Ni nanoparticles to the oil did not significantly increase the viscosity of the nanofluids.

Synthesis of a nanofluid is not simply a mixture of a liquid and nanoparticles. It requires an adequate methodology of dispersion and homogenization. The two-step method ensures good dispersion, however the sedimentation of nanoparticles is a natural phenomenon and difficult to control. Having sedimentation, it can directly affect the thermal conductivity and other properties of nanofluids, over the time. Therefore, sedimentation of nanofluids was evaluated through pictures enabling visual control of stability. Fig. 8 (a) shows some pictures of the nanofluid samples captured after of preparation and Fig. 8(b) 30 days later. After preparation, it was carried out the sedimentation method in open containers and it was observed visually sedimentation of nanoparticles. However, it is important to highlight that the samples remained stable for approximately one week.

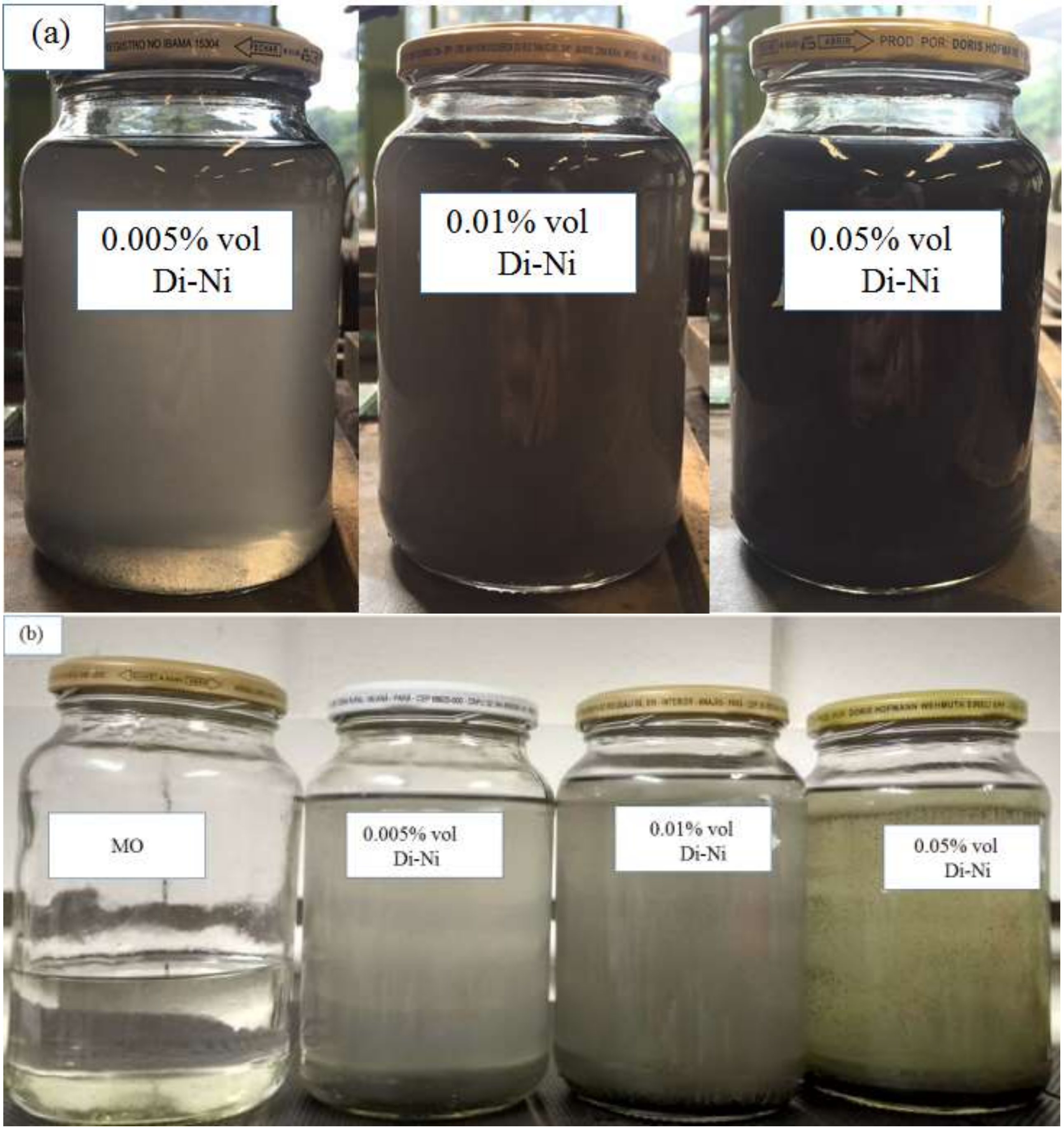

Figure 8. Photo nanofluids (a) after synthesis (b) 30 days after synthesis.

4. CONCLUSIONS

This paper reports the results of a recent investigation on the thermophysical and dielectric properties of mineral oil based Di-Ni nanofluids. Experimental measurements of the breakdown voltage, thermal conductivity and viscosity of Di-Ni nanoparticles dispersed in transformer mineral oil were carried out using low volumetric concentrations. Some specific conclusions can be addressed as follows:

- Stable Di-Ni nanofluids were successfully prepared by the two-step method with ultrasound. According to the visual method of stability evaluation, it was possible to observe that the nanofluids remained stable for approximately one week. After this period was observed almost complete sedimentation of the nanoparticles.
- The results of the breakdown voltage measurements of nanofluids revealed that these nanofluids do not provided an increase in dielectric strength of the mineral oil as reported in the literature. However it is important to observe that at low Di-Ni concentrations of the dielectric strength was not affected considerably.

- The enhancement obtained for the viscosity of the measured nanofluids was lower than 1% related to the pure oil, indicating that for this lower concentration the nanofluid can be applied.
- The thermal conductivity increased with the nanoparticle concentration as well as growing with the temperature. The increments ranging from 0.32 up to 4.47%.

Additional studies should be done before use in transformer applications, however, it is expected that positive result using nanofluids generating lighter and smaller transformer design using the same electric power.

5. ACKNOWLEDGEMENTS

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