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EFFECT OF OLEIC ACID WEIGHT FRACTION ON STABILITY OF HBN-BASED NANOFLUIDS

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Abstract.
Recently, a great variety of efforts has been made to enhance dielectric fluid properties through the dispersion of nanoparticles. However, the base fluid can only sustain a finite amount of nanoparticles, which is often insufficient to achieve the desired thermal and electrical properties. Therefore, this study intends to evaluate the weight fraction of oleic acid in hexagonal Boron Nitride (hBN) based nano-oil, which improves and optimizes the dispersion of the nanoparticles and their stability over time. Samples with weight fractions between 0.1 and 5.0 % of hBN were considered for seven different oleic acid fractions: 5.0, 7.5, 10.0, 12.5, 15.0, 17.5 and 20.0%, totaling 42 samples. Homogenization of the suspension was performed using a high intensity ultrasonic processor together with a thermostatic bath for temperature control. In order to evaluate the dispersion, each sample had its absorbance measured by a spectrophotometer, and reported for different time frames: 0, 30 and 60 days after dispersion. Moreover, photographic records were taken in order to qualitatively evaluate the dispersion and stability of each sample. The absorbance results presented an optimal value of dispersant weight fraction for almost all concentrations of hBN. Besides, an optimal weight fraction of 12.5% of oleic acid was determined for the 2.0 wt% hBN samples, resulting in a stable and well-dispersed nanofluid, after a period of 60 days. Consequently, the use of oleic acid appears to be a promising option to increase hBN nanoparticle concentration and stability in dielectric oils.

Keywords: *hBN, Dispersant, Stability, Dispersion, Oleic Acid*

1. INTRODUCTION

Miniaturization of electronic components led to increasing heat dissipating rates, demanding an improvement in heat transfer capacity, specially for passive cooling systems. In such devices, working fluids with good thermal and dielectric properties are desirable in order to help attaining proper thermal management while electrically shielding the components. However, in some of the more demanding applications, relying solely on the base fluid properties does not guarantee that the design requirements are fulfilled.

Therefore, some studies assessed the enhancement of thermal and electrical characteristics of commonly used dielectric fluids through the dispersion of nanoparticles. Considerable improvement of thermal conductivity while maintaining dielectric strength in the desirable range has been observed ((Munaro, 2017); (Krishnam et al., 2016)). Vecchia (2019) substantially enhanced the thermal conductivity of a synthetic dielectric oil by dispersing a 2.0 wt% of hBN nanoparticles, obtaining a nano-oil with a small increase in density and viscosity. Despite the promising results reported in the literature, dispersion stability remains an issue, since it deteriorates over time and depletes the heat transfer capability and dielectric strength of the suspension (Mukherjee and Paria, 2013).

It is known that nanofluids can be stabilized in many ways, and one of the state-of-the-art methods for stabilization is the addition of surfactants to diminish particles interaction and, therefore, prevent agglomeration and settling ((Krishnam et al., 2016); (Paramashivaiah and Rajashekhar, 2016)). Lv et al. (2015) studied the stability of vegetable-oil based nanofluids containing Fe3O4 nanoparticles using oleic acid as a surfactant. Through spectrum and thermogravimetric analysis, it was shown that the nanofluids with oleic acid were the most stable after 12 hours of dispersion.

In the present study, the optimal weight fraction of oleic acid in hexagonal boron nitride (hBN) based nano-oil is investigated, in order to obtain maximum dispersion stability. For the solid phase, weight fractions varying from 0.1% to 5% were considered and, for the surfactant, fractions of 5.0% up to 20.0% were evaluated. Dispersion stability was assessed through UV-vis spectrophotometry and qualitative analyses over time.

2. MATERIALS AND METHODS

In order to assess the maximum weight fraction of hBN that could be dispersed in the base fluid (MIDEL 7131), weight fractions from 0.1% up to 5.0% were considered, for seven different dispersant weight fractions: 5.0, 7.50, 10.0, 12.5, 15.0, 17.5 and 20.0%, totaling 42 samples.

MIDEL 7131 is a biodegradable synthetic dielectric fluid used in power devices for its thermal properties and insulation characteristics. At 20.0°C its density is 941.0 kg/m^3, the dynamic viscosity is 14 mm^2/s and thermal conductivity is 0.144 at 20.0°C. It has a breakdown voltage strength >75kV even for moisture levels as high as 600 ppm. The dispersed hBN nanoparticles had a purity of 99.00% of purity, with an average particle size of 137 nm, and density of 2,250 kg/m^3.

The first step of the dispersion procedure is weighting the base fluid with a precision scale Sartorius model ED224S Extend with an repeatability of 1.0×10^{-4} g. The weight fractions of oleic acid or boron nitride were determined by multiplying the weight of base fluid selected and the desired weight fraction, calculated as shown by Eq. 1:

$$m_A = m_{bf}\phi \tag{1}$$

where m_{bf} is the mass of the base fluid, m_A refers to the component to be added to it and ϕ stands for hBN or oleic acid wt%. Afterwards, the nanoparticles and the surfactant are poured into the sample, that is once more measured to guarantee that the previously established fractions were attained.

Subsequently, the samples were homogenized using a High Intensity Ultrasonic Processor, model SONICS Vibra Cell VC 750W by 1 hour straight with 50% of wave's amplitude, putting the horn's tip immersed in the sample alocated in the becker. A critical aspect of the dispersion process is the need for a precise temperature control of the samples, which was ensured by using an ultra thermostatic bath to maintain the sample contained in the copper becker at 5°C. A schematic diagram of the dispersion process is shown in Fig. 1.

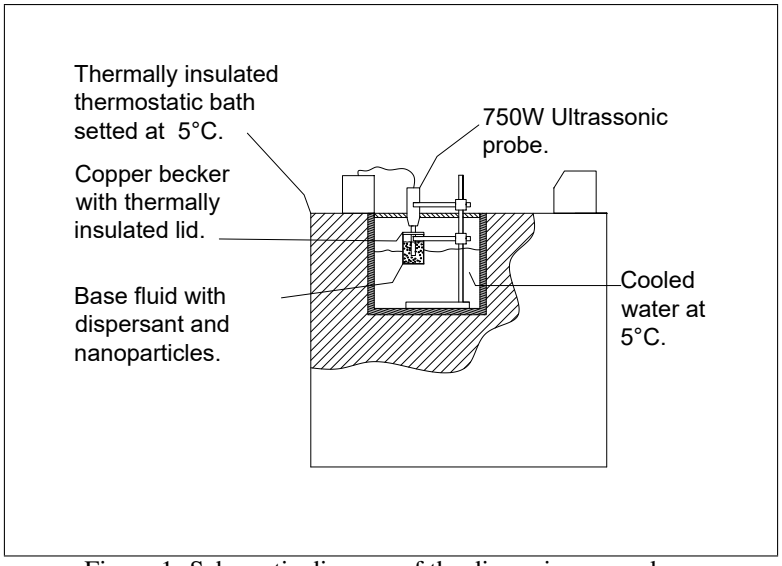


Figure 1: Schematic diagram of the dispersion procedure.

Afterwards, the absorbance of the samples was measured with a UV-vis spectrophotometer BEL LGS 53 in order to evaluate the stability of the nanofluids, according to Lambert-Beer law (Bai et al., 2014). The spectrophotometer needs to have a baseline to compare with, so it is necessary to place a base fluid sample on a transparent cuvette, then have its absorbance measured in the test section. It can be calculated by the following equation (Eq. 2):

$$A = -log_{10}\frac{\phi_e^t}{\phi_e^i} \tag{2}$$

where ϕ_e^t is the transmitted radiant power and ϕ_e^i is the incident radiant power. The procedure of measuring the absorbance was repeated, for each sample, after 30 and 60 days of its synthesis. The spectrophotometer used for absorbance analysis is presented in Fig. 2.

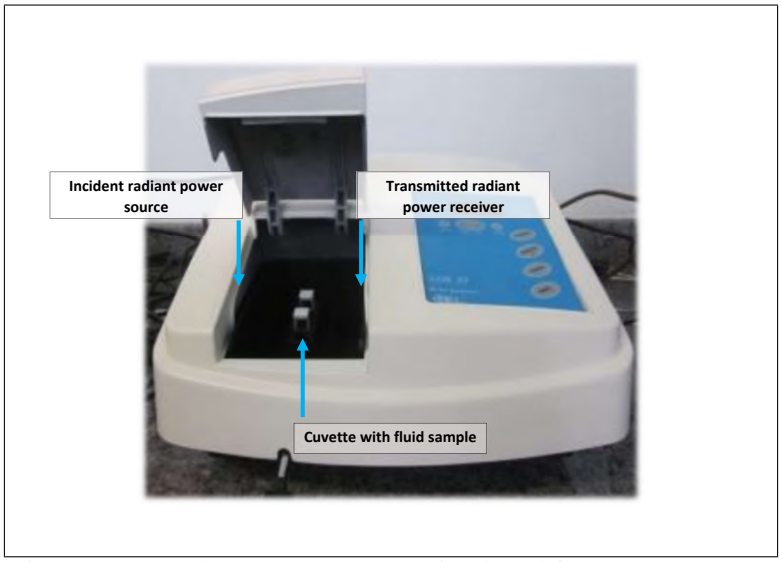
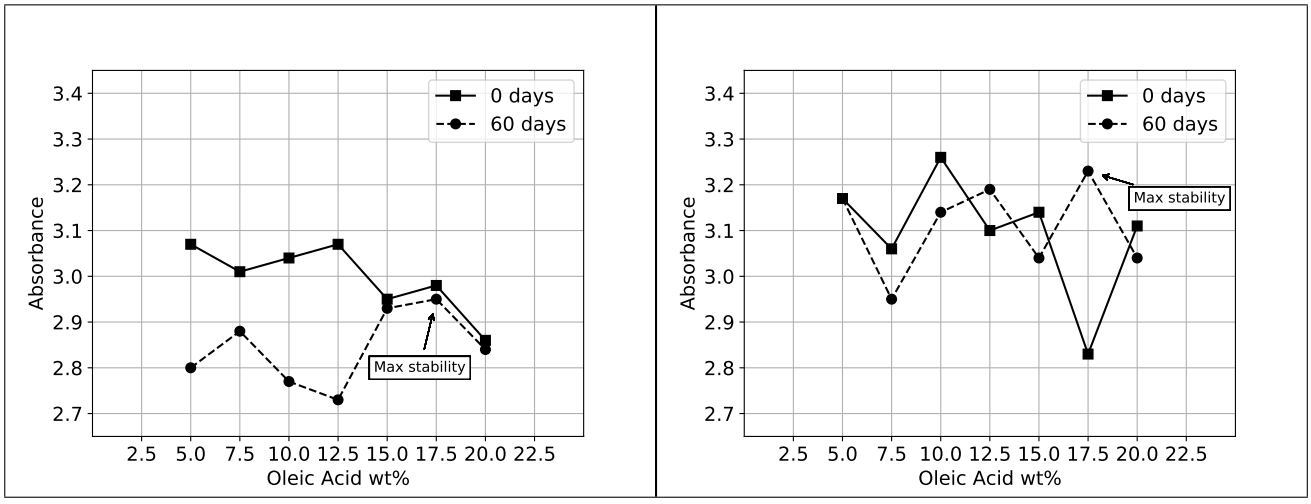


Figure 2: Spectophotometer BEL LGS 53 adapted from Wagner (2017)

3. RESULTS

Measured absorbances of 0.1 wt% hBN and 0.5 wt% hBN samples for different oleic acid weight fractions in the time span of 0 to 60 days are presented on Fig. 3. The measured values for 30 days after dispersion were omitted for better data visualization.

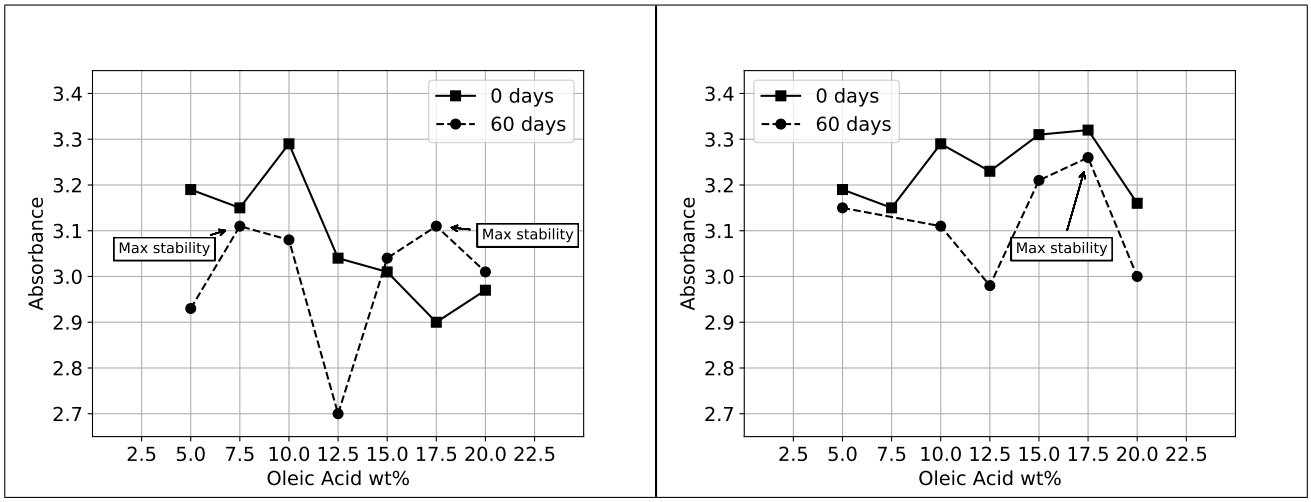


(a) hBN 0.1 wt% (b) hbn 0.5 wt%

Figure 3: Absorbance over time for samples with 0.1 and 0.5 wt% hBN in time span of 0 to 60 days

It is noticeable that the sample with 17.5 wt% of oleic acid in both graphics showed the highest absorbance levels when compared with the other fractions, after 60 days. This behavior is owed to the addition of oleic acid, that promotes an increase in the nanofluid's capability of dispersing nanoparticles, until it reaches a dispersant saturation point. From this point on, a considerable decrease in absorbance is observed, believed to be related to a depletion of the base fluid's dissolution properties, due to an excess of dispersant. Moreover, it seems that a shift in the optimal fractions of oleic acid occured after 60 days, for both hBN weight fractions. A possible explanation is that for lower concentrations of nanoparticles, the excess dispersant takes some time to sink in, so the absorbance values measured right after samples preparation might be deceiving.

Results for 1.0 and 1.5 wt% samples of hBN are presented on Fig. 4.



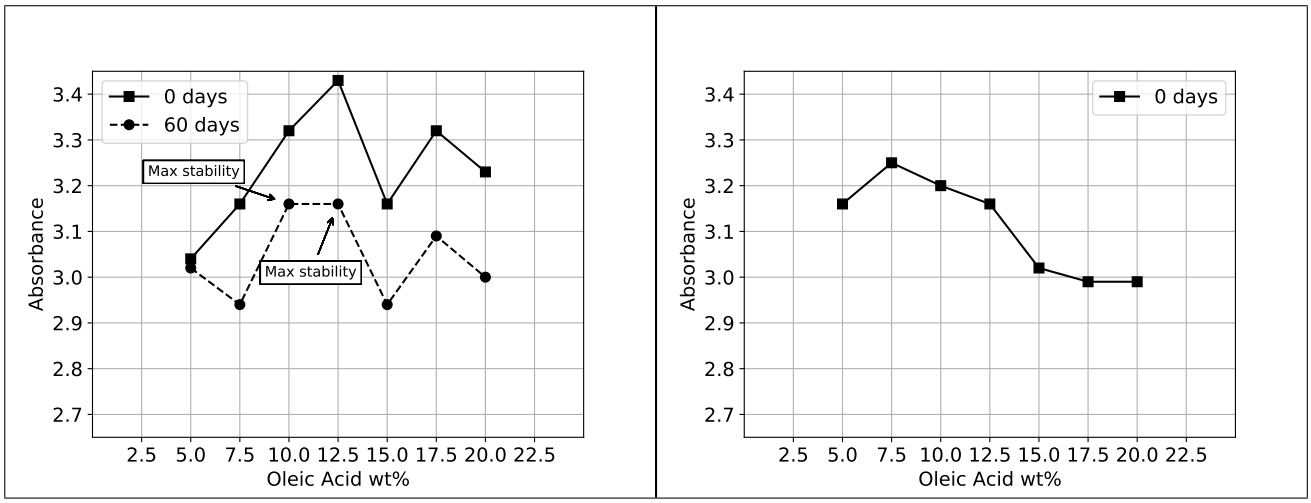
(a) hBN 1.0 wt% (b) hbn 1.5 wt%

Figure 4: Absorbance over time for samples with 1.0 and 1.5 wt% hBN in time span of 0 to 60 days

In Fig. 4a there are two points of maximum stability in the 60 days time frame,17.5 wt% and 7.5 wt%.The absorbance data measured right after dispersion for this nanoparticle concentration showed that the optimal point was of 10.0 wt% of oleic acid, however,once more, a shift in the optimal value after 60 days was observed.

The maximum stability is observed with 17.5 wt% of hBN in Fig. 4b. There is a subtle increase in the sample absorbance from 5.0 wt% until 17.5 wt% for the sample of 1.5 wt% of hBN. From this point on, the absorbance decreases, suggesting the existence of an optimal weight fraction of the dispersing agent for this specific hBN concentration. Such behavior is observed for all time frames considered. Moreover, there is a degradation of absorbance as time goes by, for all dispersant weight fractions.

The samples of 2.0 and 5.0 wt% of hBN were measured and the results are presented on Fig. 5.



(a) 2.0 wt% of hBN (b) 5.0 wt% of hBN

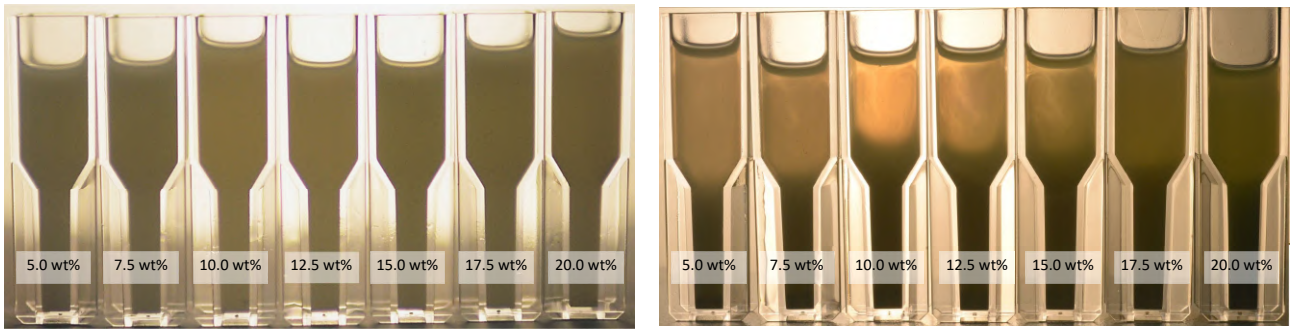
Figure 5: Absorbance over time for samples with 2.0 and 5.0 wt% hBN in time span of 0 to 60 days

In Fig. 5a there are two points of maximum stability in the last time frame, 10.0 wt% and 12.5 wt%. There are similarities between measurements taken in the different periods: for the absorbance values obtained right after dispersion, a pattern of ascending values is depicted, beginning with 5.00 wt% up until a peak value on 12.5 wt% and decreasing after that, which is also presented for the sixty days timeframe, however with two optimal points at 10.0 wt% of oleic acid.

By looking at data for the 5.0 wt% hBN concentration, it is clear that there is no dispersion of nanoparticles at all after 60 days.This behavior possibly occurred because an hBN saturation point was attained, so the oleic acid concentrations considered in this study were not sufficient to obtain a stable and homogenous sample.

Sixty days after the dispersion of nanoparticles in the base fluid,the samples which would better portrait the performance of addition of oleic acid in nanofluids were put side by side, as illustrated on Fig. 6,to assess nanoparticle's deposition patterns. As expected the nanofluids with fewer hBN particles, 0.1 wt% in the case, presented no deposition patterns, so the considered oleic acid quantitites considered were more than sufficient to ensure efficient dispersion and

stability. On the other hand, the samples containing 2.0 wt% presented superior stability over sixty days of dispersion, a remarkable result for this hBN weight fraction.



(a) 0.1 wt% of hBN (b) 2.0 wt% of hBN

Figure 6: Deposition patterns for different dispersant weight fractions after 60 days of dispersion

A qualitative analysis of the figure depicted above shows a clear deposition trend in Fig 6b, contrasting with the homogeneous appearance of Fig 6a, that contain a lower weight fraction of the nanoparticles. Furthermore, Fig. 6b represents the behavior observed in the Fig. 3a, where the samples with 10.0 and 12.5 wt% of oleic acid has shown better dispersion efficiency, while the other samples presented clear nanoparticles' settlement.

The deposition pattern in Fig 6b indicates that there is an optimal dispersant weight fraction for a given base fluid with defined nanoparticle concentration, such as the dispersion efficiency is maximized and sufficient stability is attained.

4. CONCLUSION

The development of new technologies led to the design and construction of miniaturized electronic devices that demanded an increase in heat dissipation rates. In such devices this extra energy produced by its components may deteriorate its functionality and reduce performance. Some applications rely on passive cooling to avoid this, that consists in natural circulation of fluids with good thermal and dielectric properties,in order to improve heat transfer and also protect the devices. In previous researches the use of nano sized particles ($\leq 100nm$) expressed significant results. The synthesized nanofluids had in some cases better thermal properties compared with the base fluid. Still, stability remained a matter of interest because a more stable fluid means a device with a longer lifespan and fewer costs with maintenance.

There are various ways to improve such property in the literature. One of the most promising, is the addition of oleic acid as a dispersing agent, which was chosen to be thoroughfully assessed in this study. A high intensity ultrassonic processor was used for dispersing hBN nanoparticles, altogether with a thermostatic bath to control the operating temperature of the sample, which was found to be a critical parameter in the dispersing process. Moreover,to evaluate the stability over time the absorbance values were measured with a spectrophotometer in a sixty days time span. Oleic Acid weight fractions of 5.0 to 20.0 % and Hexagonal Boron Nitride fractions of 0.1 to 5.0 % were selected and combined, totalling 42 samples, to be analized quantitatively and visually.

The absorbance results depicted optimal values of dispersant concentration for all samples considered, with the absorbance values increasing up until this inflection point, and plummeting after it. In addition, with the contribution of the dispersing agent, it was possible to disperse weight fractions(2.0 wt%) greater than those proved to be impossible to attain with minimal stability in previous studies(Dalla Vechia, 2019). Besides, the fact that the samples were stable for hBN weight fractions up until 2.0% after a sixty days period is an outstanding result.Moreover, the visual analysis of the samples corroborated the absorbance measuraments behavior presented for all samples on the study. Lower weight fractions of nanoparticles demanded no dispersant at all or even reduced quantities of it, while for considerable hBN wt% only at higher dispersant concentrations a stable dispersion was obtained.

Furthermore,the thermal and electric properties of enhanced hBN nano-oil samples with oleic acid have to be measured in order to determine if the presence of the dispersing agent has any influence over these key parameters. Such assessment is paramount to establish such nanofluid as a reliable and efficient option regarding electronics cooling. Future works may as well benefit from using hBN nanoparticles with smaller particle sizes, once in previous studies this has shown to be a relevant parameter do dispersion effectiveness.

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6. RESPONSIBILITY NOTICE

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