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Study of oleic acid capped-nanoparticles dispersion in the conventional lubricant oil

Rajan Kumar[1], Kalpana Sachan[2], Anoop Pratap Singh[3]

[1]*IES College of Technology, Bhopal, India*
[2]*Rabindranath Tagore University Bhopal, India*
[3]*Bansal Institute of Science and Technology Bhopal, India*

Abstract

Nanolubricants, enhanced with nanoparticles, have gained significant attention due to their potential to improve lubrication performance and thermal stability. This study investigates the sedimentation behavior of Al_2O_3, CuO, and SiO_2 nanoparticles in nanolubricants through a pictorial analysis, providing crucial insights into their dispersion stability over time. The experimental results indicate that Al_2O_3 nanoparticles, at a concentration of 0.05 wt.%, begin to settle around the 12th day after formulation. In contrast, CuO and SiO_2 nanoparticles exhibit superior stability, with initial sedimentation occurring around the 28th day for the same concentration. Additionally, the study reveals that increasing nanoparticle concentration accelerates the sedimentation process, thereby reducing the overall stability of the nanolubricants. These findings contribute to a better understanding of nanoparticle interactions within lubricant formulations, aiding in the development of more stable and effective nanolubricants for various industrial applications.

*Keywords***:** *Oleic acid, Nanoparticle, Al_2O_3, CuO, SiO_2, Conventional lube oil.*

1. Introduction

Nanoparticles have garnered significant attention in tribology due to their potential to improve the performance of lubricant oils. Adding nanoparticles to conventional oils enhances their anti-wear and friction-reducing properties [1], [2], [3].Various nanoparticles, including those made of metals, nonmetals, and carbon derivatives, are combined with lube oil to evaluate their performance. Examples of these nanoparticles include Cu, CuO, Al, Al_2O_3, diamond, and carbon nanotubes (CNTs). These nanoparticles are mixed with different base oils such as Polyalphaolefin (PAO), engine oil (5W30), diesel engine oil (SAE 30), and mineral oil (SN 650), among others. The typical size of these nanoparticles is less than 100 nm. When nanoparticles are added to lube oil, they can significantly enhance the tribological properties and thermal performance of the oil [4], [5].

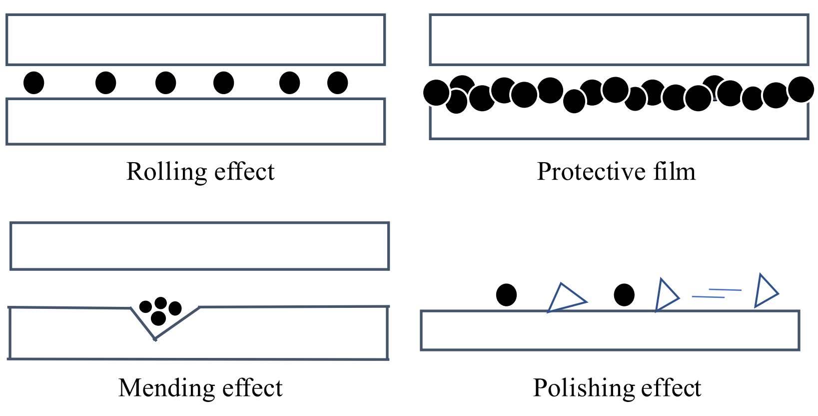


Figure 1. Mechanism of nanoparticles within the tribological surfaces

There is a question that arises in every mind with the different composition means a lube oil is a liquid substance and a nanomaterial is a solid substance then how can this mismatch improve the performance. This can be easily understood by the mechanism of the nanoparticles in between the tribological surfaces [2], [6], [7], [8]. This can be elaborated by Fig. 1. As shown in the figure nanoparticles act as the tiny balls in between the tribo surfaces which

E-mail ID: rajankumar227@gmail.com

convert sliding motion into rolling results lower the value of COF [7], [9]. It can make a protective film over the tribo surface which prevents the direct rubbing of tribo surfaces which leads to lower the COF [10], [11], [12] As materials at the nano level have a large number of asperities and friction cracks even it looks smooth. Tiny balls of nanoparticles fill these cracks and make the tribe surface smoother [13]. In many cases, tribo surfaces can improve their surface roughness due to the seizure action of hard nanoparticles. This is also termed the polishing effect of the nano [14], [15], [16]. However, the efficiency of these additives depends on the stability of their dispersion. Agglomeration and sedimentation often limit the practical application of nanoparticles in lubricants. Surface modification using capping agents like oleic acid offers a promising solution to enhance dispersion stability and performance.

The aim of this study is to analyze the dispersion behavior of oleic acid-capped nanoparticles (Al_2O_3, CuO, and SiO_2) in conventional lubricating oil. The dispersion analysis is done with the help of visual analysis of high-quality images of the nano lubricant at different time segments.

2. Materials and Methods

2.1. Materials

The study utilized nanoparticles composed of aluminum oxide (Al2O3), copper oxide (CuO), and silicon dioxide (SiO2) [5], [17], [18], [19]. These nanoparticles exhibit an average size range of 30 to 50 nanometers and maintain a spherical morphology. This data, including the size and shape of the nanoparticles, was obtained from the supplying company, NRL Jharkhand, from which these nanoparticles were procured. Oleic acid was employed as a dispersion element to enhance the stability of the nanoparticle dispersion[20]. Conventional lubricant oil, specifically Castrol 5W-40, served as the base oil for the formulation of the nano-lubricant.

2.2. Method

The surface modification process commences with the addition of oleic acid, constituting 10% of the weight of the nanoparticles, to a solution of 50 ml of ethanol. This mixture is then subjected to stirring in a 250 ml beaker at a temperature of 60 °C, using a magnetic stirrer set to a speed of 700 revolutions per minute (rpm) for a duration of 5 minutes. As depicted in Figure 2 (a), this step involves a magnetic stirrer in conjunction with the oleic acid and ethanol mixture.

Following the initial blending of oleic acid and ethanol, 10 grams of nanoparticles are introduced into the solution. This enhanced mixture is subsequently stirred continuously at 60 °C and 700 rpm for a period of 2 hours, as illustrated in Figure 1 (b), which demonstrates the incorporation of nanoparticles into the oleic acid and ethanol solution.

At the conclusion of the 2-hour stirring process, a viscous mixture is obtained. This viscous mixture is then subjected to heating in a hot air oven set at 80 °C for 4 hours. Ultimately, this process results in the formation of a dry powder of oleic acid-capped nanoparticles. This entire surface modification procedure is meticulously carried out separately for each type of nanoparticle to ensure precise and consistent results [20].

The dispersion analysis is conducted through a meticulous visual examination of high-quality images of the nanolubricant samples. To facilitate this analysis, 10 ml of the nanolubricant is preserved over a period of one month. After this preservation period, the samples are analyzed to assess the dispersion characteristics. This detailed examination allows for the identification and evaluation of the stability and uniformity of the nanoparticles within the lubricant, ensuring that the dispersion quality meets the required standards.

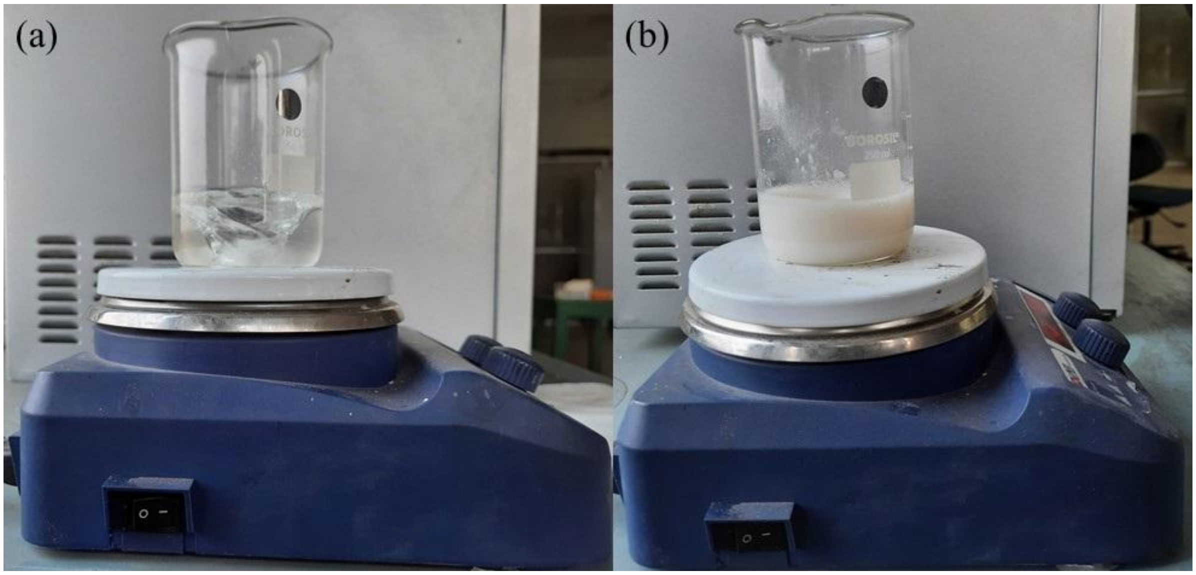


Figure 2. (a) Magnetic stirring of oleic acid and ethanol, (b) Magnetic stirring of Al_2O_3 nanoparticles in the solution of oleic acid and ethanol

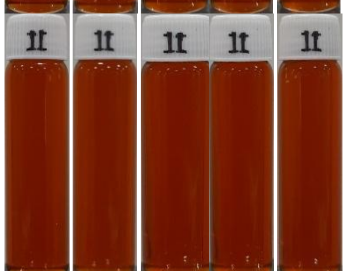
3. Results

The meticulous examination of images highlighting the dispersion of various nanoparticles within lube oil is carried out with exceptional precision. Drawing upon the author's extensive research into nano lubricants, the study primarily focuses on evaluating the stability of nanoparticles dispersed within the base oil. Specifically, the dispersion of Al_2O_3, CuO, and SiO_2 nanoparticles was analyzed through images taken over different intervals: 3 days, 6 days, 15 days, and 30 days. The findings from this comprehensive analysis are recorded under the 'Observation' column in Table 1. This table effectively showcases the images of the nano lubricants at various time scales, providing a clear visual representation of the dispersion stability over time.

Table 1. Images of nano lubricant samples at different nanoparticles with conventional lube oil

Duration	0 Days	3 Days	6 Days	15 Days	30 Days	Sedimentation Starts (Days)	Observation
Conventional Oil		-	-	-	-	-	Redish in color
Al_2O_3 (0.05%)						12	Sedimentation particles were observed after 12 days. No color change was observed.

Duration	0 Days	3 Days	6 Days	15 Days	30 Days	Sedimentation Starts (Days)	Observation
Al_2O_3 (0.01%)						12	Sedimentation particles were observed after 12 days. No color change was observed.
Al_2O_3 (0.25%)						6	Sedimentation particles were observed after 6 days. No color change was observed.
Al_2O_3 (0.5%)						6	Sedimentation particles were observed after 6 days. No color change was observed.
CuO (0.05%)						5	The blackish color of the nano lubricant confirms the presence of CuO even after 30 days.
CuO (0.1%)						5	The blackish color of the nano lubricant confirms the presence of CuO even after 30 days.

Duration	0 Days	3 Days	6 Days	15 Days	30 Days	Sedimentation Starts (Days)	Observation
CuO (0.25%)						4	A clear dark black color of the nano lubricant was observed. Some visible color change occurs after 15 days. However blackish color can be observed even after 30 days.
CuO (0.5%)						4	A clear dark black color of the nano lubricant was observed. Some visible color change occurs after 15 days. However blackish color can be observed even after 30 days.
SiO_2 (0.05%)						28	A clear and homogeneous mixture was observed with no color change from the base oil.
SiO_2 (0.1%)						28	A clear and homogeneous mixture was observed with no color change from the base oil.
SiO_2 (0.25%)						20	A clear and homogeneous mixture was observed with no color change from the base oil. Some sedimentation was observed after 20 days.

Duration	0 Days	3 Days	6 Days	15 Days	30 Days	Sedimentation Starts (Days)	Observation
SiO_2 (0.5%)						20	A clear and homogeneous mixture was observed with no color change from the base oil. Some sedimentation was observed after 20 days.

Table 2 provides a comprehensive summary of the sedimentation behavior of nanoparticles within conventional lubricant oil. The representation of Nano Balls visually illustrates the initiation of nanoparticle sedimentation. Specifically, the Al_2O_3 nanoparticles begin to settle after approximately 15 days. This overview serves as an initial insight into the stability of nanoparticles in nanolubricants and offers a fundamental basis for further investigative analysis regarding their long-term dispersion and performance characteristics.

Table 2. Nanoparticles sedimentation summary

Nanoparticles	0 Days	3 Days	6 Days	15 Days	30 Days
Al_2O_3 (0.05%)					
Al_2O_3 (0.1%)					
Al_2O_3 (0.25%)					
Al_2O_3 (0.5%)					
CuO (0.05%)					
CuO (0.1%)					
CuO (0.25%)					
CuO (0.5%)					
SiO_2 (0.05%)					
SiO_2 (0.1%)					
SiO_2 (0.25%)					
SiO_2 (0.5%)					

4. Conclusions

This study presents a detailed pictorial analysis of nanoparticle sedimentation within nanolubricants, providing valuable insights into their stability over time. The experimental findings indicate that Al_2O_3 nanoparticles, at a concentration of 0.05 wt.%, begin to settle as early as the 12th day after the formulation of the nanolubricant. In contrast, CuO nanoparticles exhibit excellent stability characteristics, with sedimentation initiating around the 28th day for the same concentration. A similar trend is observed in SiO_2 nanoparticles, demonstrating prolonged dispersion stability. Furthermore, the study highlights a critical correlation between nanoparticle concentration and sedimentation time, revealing that an increase in nanoparticle concentration leads to a faster sedimentation process. These findings provide a fundamental understanding of nanoparticle behavior in lubricant formulations, which can guide the development of more stable and efficient nanolubricants for industrial applications.

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