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Rheological Properties Enhancement of Commercial Lubricating Oils via Different Nanoparticles Oxides

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ABSTRACT

This research addresses by evaluating the individual and synergistic effects of zinc oxide (ZnO) and silicon dioxide (SiO_2) nanoparticles when incorporated into (10W-30) and (10W-40) commercial oils to upgrade their performance. The nanomaterials were synthesized via the sol–gel technique, yielding high-purity particles (99.9% for ZnO and 98.0% for SiO_2) with well-defined parameters. The diameters and surface areas of ZnO and SiO_2 particles were 55–95 nm and 40–60 nm, 65 m^2/g and 160–200 m^2/g, respectively. In terms of attempting to reach the best concentration, 1.0 % by weight concentration was used of each nanomaterial (after testing different ratios). A two-stage preparation procedure was used to obtain a stable nano-lubricant at room temperature. Firstly, a magnetic stirrer was used with the addition of oleic acid. Secondly, a high-speed mixer was used. The results confirmed a noticeable enhancement in the physical properties of the nano-lubricants. The viscosity index was recorded to be improved from 118.2 to 120.1 and 121.8 for ZnO/10W-30 oil and SiO_2/10W-30 oil, respectively. For ZnO/10W-40 and SiO_2/10W-40, the viscosity index rose from 117.2 to 122.5 and 119.3, respectively. For the hybrid formulation, the mix of 0.75 wt.% ZnO/0.25 wt.% SiO_2 was used (the best hybrid concentration yielded 1.0 % after experiencing different ratios) with both oil grades, 10W-30 and 10W-40, the viscosity index was 122 and 119, respectively. It was concluded that nanoadditives could be the solution to the shortcomings in the performance of commercial oils by raising the viscosity index, flash point, and reducing the pour point.

Keywords: Commercial lubricants oil, ZnO and SiO_2 nanomaterials, Pour point, Flash point, Viscosity index.

1. INTRODUCTION

Modern demands for a clean environment, reduced pollution and energy waste, as well as cost reduction, have led researchers to focus on the types of fuels and lubricating oils used in vehicles and engines in general to reduce wear and frictional losses and unnecessary heat production **(Ali et al., 2016; Dai et al., 2016)**. To achieve the aforementioned goals, aligned

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with the development of industry and machinery sectors, it becomes necessary to upgrade materials used, especially lubricating oils **(Ingole et al., 2013; Wang et al., 2023)**. To mitigate vehicle emissions, using sustainable materials and controlling fuel combustion are considered serious solutions. One of the keys to these solutions was lubricating oils. The primary reasons for using lubricating oils are to reduce fuel consumption inside engines that operate in a harsh environment of temperature and pressure, which leads to energy waste and engine inefficiency, causing pollution. Many additives are incorporated into base lubricating oils to enhance their performance, such as detergents, dispersants, antioxidants, friction modifiers, rust and corrosion inhibitors, viscosity index improvers, foam inhibitors, and pour point depressants **(Mathura, 2025)**. In the local market, there are a large number of types of lubricating oils, some of which lack standard specifications. One of the novel and effective solutions for upgrading the specifications of lubricating oils is the incorporation of nanoadditives into them **(Cortes et al., 2020)**. Nanoparticles generally possess 1 to 100 nanometers in dimensions, have unique characteristics that give them a distinctive effect **(Esfe et al., 2019; Peña-Parás et al., 2015)**. Modern research work investigates employing nanoscale particles to enhance the performance of lubricants through reducing wear and high-pressure effects, and controlling viscosity **(Ryskin et al., 1988; Demas et al., 2017; Ilie and Covaliu, 2016; Ettefaghi et al., 2013; Zin et al., 2014; Hadi et al., 2018)**. Zinc oxide (ZnO), titanium dioxide (TiO_2), silicon dioxide (SiO_2), and aluminum oxide (Al_2O_3) have been recently identified for optimizing the rheological and tribological properties of base lubricating oils by improving flow characteristics and reducing wear **(Ali and Salam, 2020; Kao et al., 2009)**. Generally, incorporating nanoparticles should not exceed around 1.0 wt.%, because higher concentrations may cause unstable particles that agglomerate and easily sediment, which results in inefficient lubricant **(Bakunin and Parenago, 2004; Darminesh et al., 2017; Xue et al., 2015)**. **(Desai et al., 2021)** studied the thermo-physical properties of SAE20W40 engine oil mixed with SiO_2 nanoparticles in five different concentrations, i.e. 0.3%, 0.6%,0.9%, 1.2% and 1.5wt.% properties, like kinematic viscosity, a flash point, fire point, and thermal conductivity, have been experimentally studied. **(Mousavi et al., 2021)** compared the tribological and thermophysical features of the lubricating oil using MoS_2 and ZnO nano-additives in three different concentrations (0.1, 0.4, and 0.7 wt.%) in commercial diesel oil. Properties such as viscosity, viscosity index, flash point, and friction coefficient of the resulting nano lubricant were evaluated and compared **(Fahad and Abdul Majeed, 2022).** The main objective of this study was to investigate the effect of TiO_2 and CuO nanoparticles, individually and in hybrid TiO_2-CuO, on the thermal and physical properties, such as kinematic viscosity, viscosity index, pour point, and flash point, of Iraqi base oil (40 stock) at 40 °C and 100 °C for different concentrations (0.2, 0.5, 0.8, 1.0wt.%) NPs. It was found that the oil's properties were improved at the hybrid concentrations of NPs (CuO/TiO_2) at (0.8 and 1.0wt.%). **(Sharif et al., 2023)** aimed to assess the impact of these nanoparticles on the viscosity and coefficient of friction (COF) of the nano lubricant Double End Capped Polyalkylene Glycol oil (DEC-PAG). Three different nano lubricants were synthesized through a two-step process, including mono-nano lubricants (Al_2O_3) and (SiO_2), and hybrid nano lubricants (Al_2O_3-SiO_2). The dynamic viscosity, viscosity index, and coefficient of friction (COF) of all the nano lubricants were improved at volume concentrations (0.01,0.03,0.05vol.%). The results showed that the nanoparticles, temperature, and volume concentration significantly influenced the viscosity index and COF of nano lubricants. **(Revalina et al., 2024)** added Zinc Oxide (ZnO) at different concentrations (0.01, 0.02, 0.05wt.%) to commercial lubricant oil (10W-40) and studied their effect on the kinematic viscosity and viscosity index changes that occur in engine lubricants.

The limitation of the current study is that the nanoparticles approach was used to enhance the rheological properties of commercial oils that suffer from performance deficiency. ZnO, SiO_2, and their blend were chosen to investigate their effect on the rheological properties of commercial lubricants (10W-30) and (10W-40).

2. EXPERIMENTAL WORK

2.1 Materials

SAE 10W-30 and 10W-40 commercial engine oils were provided from the market as base materials, with detailed specifications and properties of these oils provided in **Table 1**. Zinc acetate dihydrate (purity ≥ 99.5%), the base material for ZnO NPs synthesis, was provided by BDH Chemicals Ltd., Poole, England. Sodium hydroxide (NaOH) with a purity of at least 98%, from Alpha Chemika, India, was used in the synthesis of ZnO NPs. Ethanol (99.8%) purity was used in the synthesis of ZnO NPs, and methanol (99.8%) purity was used in the synthesis of SiO_2 NPs; both were provided by BDH Chemicals, England. Acetic acid (99.5%) purity was used in the synthesis of SiO_2 NPs, provided by BDH Chemicals Ltd., Poole, England. Tetraethyl orthosilicate (TEOS) of 98% purity was used as the substrate for the preparation of SiO_2 NPs manufactured by Sigma-Aldrich, USA. Oleic acid (≥ 99%) purity was used as a surfactant to increase the dispersion of nanomaterials during the preparation of nano-lubricant oils manufactured by Sigma-Aldrich. Distilled water was used to dilute the nanomaterials, which had total dissolved solids (TDS) of 2 mg/L and electrical conductivity of 4 µs/cm, in all experimental procedures.

Table 1. Specifications of SAE (10W-30) and (10W-40) commercial oils.

Specifications	SAE (10W-30)	SAE (10W-40)
Density at 15 °C (kg/m^3)	886	888
Flash Point (°C)	228	230
Pour Point (°C)	-9	-15
Viscosity Index	118.2	117.2
Kinematic Viscosity at 100 °C (cSt)	13.8	14.1
Kinematic Viscosity at 40 °C (cSt)	98.0	108.5

2.2 Equipment

The equipment used in the experimental procedures included the following: A magnetic stirrer with a heating plate (HS-860 model, Alpha Co., Iran), used to mix the nanomaterial with lubricating oils as a preliminary step, along with oleic acid. A high-speed digital mixer (OS40-Pro, Darwell Laboratory Research Co., China), used to mix the nanomaterial with oils to produce nano-lubricant oil. A specific gravity meter (Alpha Co., 0.8-0.9 g/cm^3 range, France), used to measure the density of the oils before and after the addition of the nanomaterials. A drying oven (HP-ADO30, China) for calcining the nanoparticles. Standard laboratory glassware from Schott, Duran, Germany, was also used throughout the preparation and blending processes.

2.3 Procedure

2.3.1 Preparation of Nanoparticles

Zinc oxide (ZnO) nanostructures were synthesized using the sol–gel technique. First, 2 g of zinc Acetate dihydrate (≥ 99% purity) was dissolved in 15 ml of distilled water. In a separate container, 8 g of Sodium hydroxide (≥ 98% purity) was mixed with 10 ml of distilled water, and both solutions were stirred for about five minutes. Afterwards, 100 ml of Ethanol was slowly added drop-wise to the combined solution at ambient temperature. The appearance of a white precipitate indicated the completion of the reaction. After calcination at 500°C for about 5 hr, ZnO nanoparticles were obtained, in agreement with the procedure **(Hasnidawani et al., 2016)**. For the preparation of silicon dioxide (SiO_2), 20 ml of methanol (CH_3OH) was mixed with 2.3 ml of Acetic Acid (CH_3COOH) and stirred for five minutes at room temperature. After that, 1.5 mL of tetraethyl orthosilicate (TEOS) was added drop by drop at room temperature. Then the mixture was stirred for 90 minutes until a transparent homogeneous solution appeared. After which it entered calcination at 500°C for 5 hr. The product was converted to SiO_2 nanoparticles. A fine white powder was obtained **(Saravanan and Dubey, 2020)**.

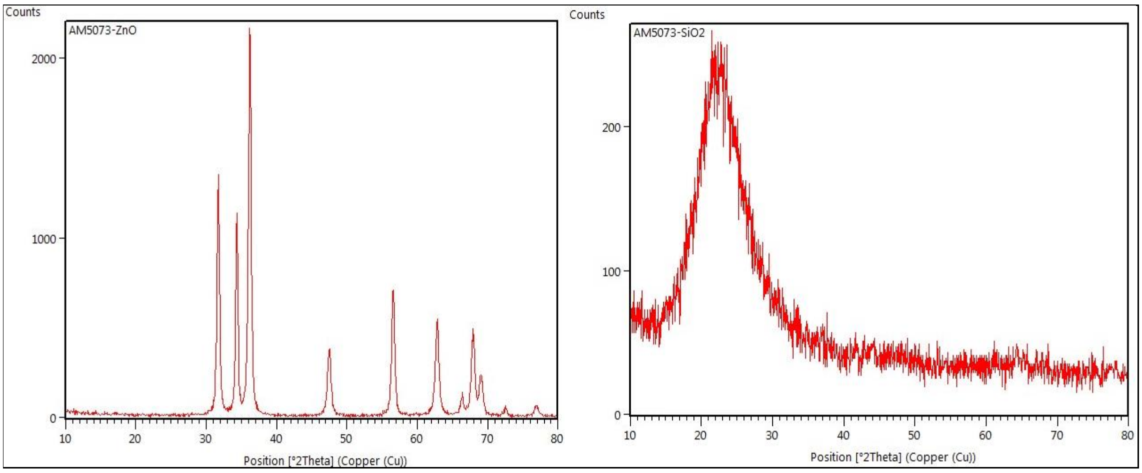
2.3.2 Preparation of Nano-lubricant

Our earlier study showed that a 1.0 wt.% concentration of nano additives gave the highest rheological properties **(Hadi and Almilly, 2026).** Thus, only 1.0 wt.% concentration of nano additives was adopted in this study for ZnO and SiO_2 alone and for their mixture. Our earlier experiments about different mixtures of ZnO and SiO_2 showed that 0.75% ZnO and 0.25% SiO_2 gave the best rheological properties among other blends**.** Therefore, only this blend was applied to the studied commercial oils (10W-30 and 10W-40). To incorporate 1.0 wt% ZnO and SiO_2 nanoparticles into commercial lubricating oils, 100 ml of the oils was used. Two-stage stirring was used: by a magnetic stirrer at 1000 rpm for 2 hours and by a high-speed mixer at 2000 rpm for another 2 hours. Oleic acid was added as a surfactant to achieve a uniform and stable dispersion at room temperature. By visual observation, no sedimentation of nanoparticles occurred.

3. RESULTS AND DISCUSSION

3.1 The Characterization of the Nanoparticles by X-ray Diffraction (XRD)

The X-ray diffraction (XRD) analyzer from (Philips PW1730, Netherlands), used to analysis of the ZnO nanoparticles revealed sharp diffraction peaks in **Fig. 1(a)**, well-defined peaks corresponding to the (100) with 31.7°, (101) with 36.2°, (102) with 47.5°, (110) with 56.6°, (103) with 62.8°, (200) with 66.4°, (112) with 67.9° and (201) with 69.1°planes, confirming a highly ordered, crystalline nature and successful synthesis of high-purity ZnO NPs free crystalline impurities. This high purity is essential for preventing unwanted chemical reactions and ensuring reliable performance. The inherent crystalline structure and high crystallinity give the necessary mechanical strength and structural stability under high shear and elevated temperature **(Chen et al., 2017; Mousavi and Heris, 2020; Mousavi et al., 2021; Desai et al., 2021)**. As illustrated in **Fig. 1(b)**, the XRD pattern of the SiO_2 nanoparticles displays a characteristic, by a distinct combination of amorphous and crystalline phases. The most prominent feature is the broad "amorphous hump" centered between 20° and 30°(2θ), which indicates a significant silicate network typical of silica gel or glass. Superimposed on this broad base are several sharp, narrow diffraction peaks which confirm the presence of a long-range ordered crystalline phase, specifically identified as Alpha-Quartz. The highest intensity reflection occurs at 26.6° (2θ), corresponding to the (101) lattice plane, which is the primary diagnostic peak for quartz. Coexistence of the broad background and sharp peaks implies that the sample is a composite material where quartz micro-crystals are embedded within an amorphous silica matrix. This quantitative profile is essential for determining the degree of crystallinity, identifying the mineralogical purity of the SiO_2 **(Sepehrnia et al., 2024),** which leads to improved lubricant oil specifications.

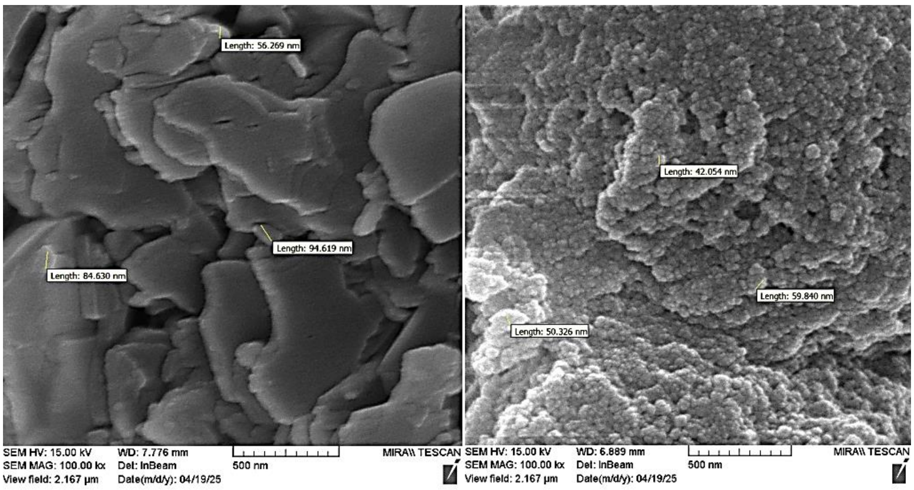


(a) (b)

Figure 1. The XRD Characterization of (a) ZnO and (b) SiO_2 NPs.

3.2 Morphological Investigation of Nanoparticles via Scanning Electron Microscopy (SEM)

Scanning electron microscopy (SEM) using a (Tuscan MIRA III, Czech) was employed to examine the structural characteristics of the ZnO and SiO_2 nanoparticles. **Fig. 2(a)** illustrates a homogeneous distribution of ZnO nanoparticles, which confirms a successful synthesis procedure. However, ZnO nanoparticles show irregular surfaces of rough morphologies. The thick configuration of the particles with interconnections supposes a high surface thickness, which improves their shear resistance **(Saravanan and Dubey, 2020; Chen et al., 2017; Mousavi and Heris, 2020; Mousavi et al., 2021)**.



(a) **(b)**

Figure 2. The SEM of (a) ZnO and (b) SiO_2 NPs

The surface morphology and structure of SiO_2 nanoparticles, as shown in **Fig. 2(b),** show nearly uniform spherical-like particles with some observable porosity at the nanoscale. While silicon dioxide is typically amorphous, drying and heat treatment lead to the formation of fine crystalline domains **(Saravanan and Dubey, 2020; Chen et al., 2017)**. The NPs' morphology affects the rheological properties of lubricants by optimizing dispersion within the oil, rolling between surfaces, and resisting shear.

3.3 Energy Dispersive X-ray Spectroscopy (EDS) of NPs

Energy-dispersive X-ray (EDS) spectroscopy validated the elemental integrity of the synthesized nanoparticles, where the special presence of zinc and oxygen signals supported the formation of pure ZnO. Quantitative evaluation **Fig. 3(a)** indicated a composition containing 86.59% at oxygen and 13.41% at zinc, on an atomic basis. The corresponding values by mass were 61.25 wt.% and 38.75 wt.%, respectively. The automated identification of the spectra further corroborated these results, exhibiting prominent characteristic peaks for oxygen at the Kαline (0.535 keV) and zinc at the Kαline (1.025 keV) **(Kalyani et al., 2015; Heer, 2017; Taha-Tijerina et al., 2018; Salem et al., 2009)**.

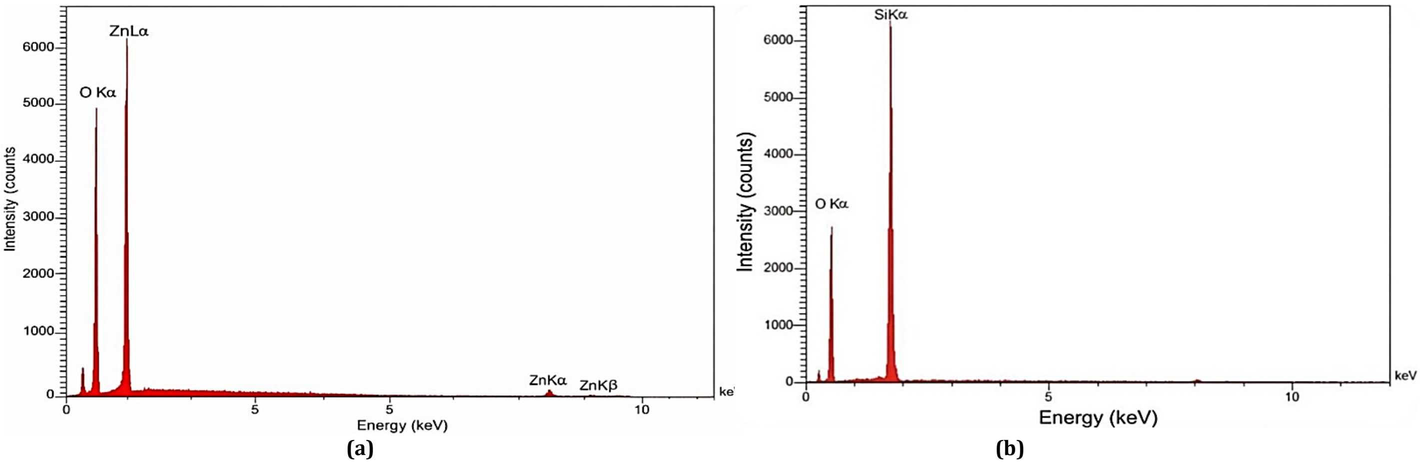
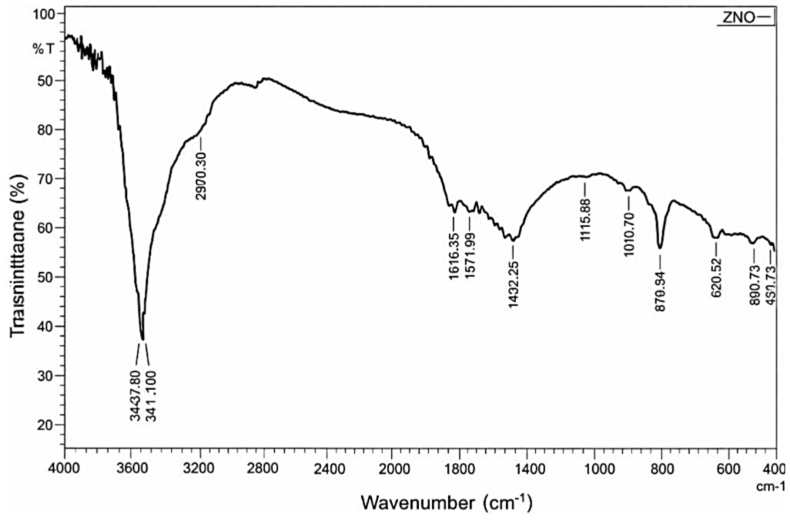


Figure 3. EDS analysis of (a) ZnO and (b) SiO_2 NPs.

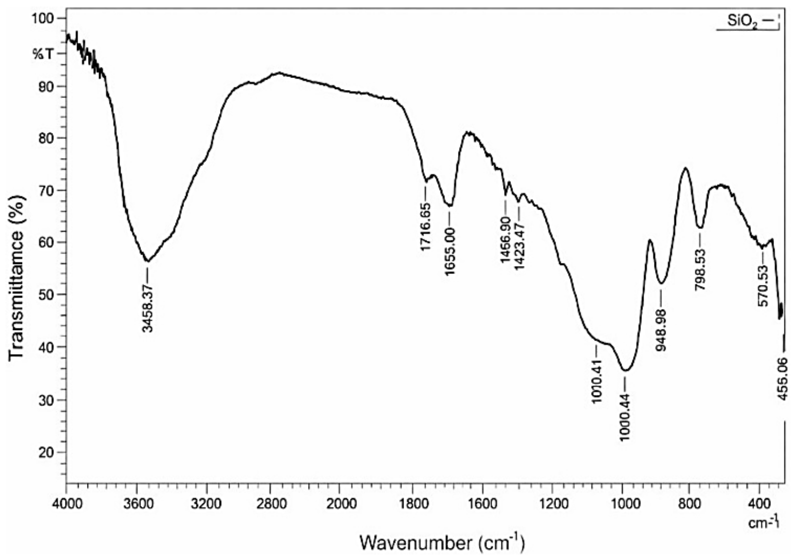
The EDS of the SiO_2 nanoparticles was verified, confirming that silicon and oxygen are the primary constituents of the synthesized sample. As illustrated in **Fig. 3(b)**, quantitative data established the composition of the atomic contained 52.32% for silica and 47.68% for oxygen, and mass basis were 65.83 wt.% silicon and 34.17 wt.% oxygen. These findings were supported confidently by the automated peak identification, which highlights a dominant silicon signal at the Kα energy level of 1.765 keV, accompanied by a clear oxygen peak at 0.545 keV **(Cortes et al., 2020; Mariño et al., 2016)**. High purity of NPs ensures uniformity of their properties and the ability to assess their performance as additives to the lubricants.

3.4 Fourier Transform Infrared (FT-IR) Spectroscopic Investigation of the Prepared Nanoparticles

The Fourier-Transform Infrared Spectroscopy (FTIR) for the ZnO and SiO_2 nanoparticles provides insights into their chemical bonds and surface characteristics. In **Fig. 4(a),** the peak at 3473.80 - 3414.00 cm^{-1} corresponds to a very broad and strong absorption band which is characteristic of the O-H stretching vibration. This typically indicates the presence of a little water on the surface of the ZnO nanoparticles (due to the high surface area). The surface hydroxyl groups (O-H at 3473.8 cm^{-1}) are highly active sites that make ZnO surface hydrophilic. The peak at 1616.35 cm^{-1} is generally attributed to the H-O-H bending vibration of the adsorbed water molecules; this region might also contain signals from C=O or C=C bonds. Peaks below 700 cm^{-1} (690.52, 621.08, 522.71, 486.13, and 430.13 cm^{-1}) are characteristic of the Zn-O stretching vibration modes, confirming the successful synthesis and crystalline nature of the zinc oxide structure. The surface hydroxyl groups (O-H at 3473.8 cm^{-1}) are highly active sites that make ZnO surface hydrophilic. When ZnO nanoparticles are dispersed in a nonpolar base oil, the active sites improve dispersion stability and reduce agglomeration **(Chen et al., 2017; Hernaiz et al., 2023; Mariño et al., 2023)**.



(a)



(b)

Figure 4. FT-IR spectroscopy of (a) ZnO and (b) SiO_2 NPs.

The FTIR of the SiO_2 sample in **Fig. 4(b)**. displayed a peak at 1653.00 cm^{-1} that is primarily attributed to the H-O-H bending vibration of the physically adsorbed water, supporting the assignment of the broad O-H peak. Peak at 948.98 cm^{-1} is assigned to the stretching vibration of the surface silanol group (Si-OH). Its intensity directly reflects the concentration of these active sites. The high concentration of surface silanol (Si-OH) groups at the strong peak of 3458.37 cm^{-1} and the peak at 948.98 cm^{-1} indicates that the SiO_2 nanoparticles are highly hydrophilic. For successful application in engine oil, the SiO_2 must be functionalized—typically by grafting an organosilane (containing long alkyl chains) onto the Si-OH sites. Successful modification would be confirmed by the dramatic reduction or elimination of the O-H peaks and the appearance of strong C-H stretching peaks in the 2800-3000 cm^{-1} region, indicating a stable, hydrophobic surface crucial for good oil dispersion and optimal rheological properties **(Saravanan and Dubey, 2020; Mariño et al., 2023)**.

3.5 Zeta-Potential Analysis of (ZnO and SiO_2) NPs

The Zeta potential analysis serves as a vital diagnostic tool for evaluating the stability of nanofluids. It works by quantifying the electrical potential gap between the bulk dispersion medium and the thin, stationary fluid layer enveloping each particle. When this potential is sufficiently high, it creates powerful repulsive forces that keep particles from clumping together **(Ajeena et al., 2022)**. Essentially, while high absolute values correlate with long-term suspension stability, lower readings often signal particle agglomeration and sedimentation. A particle size analyzer device determined the zeta-potential (Zeta Plus, Holtsville, New York 11742, USA). **Fig. 5 (a, b, and c)** shows the zeta-potential values for (ZnO = -19.15 mV, SiO_2 = 23.16 mV, and hybrid ZnO/SiO_2 = 32.32 mV) in SAE (10w-30) lubricant oil. For these results, NPs are considered stable because the zeta potential is greater than +10 and less than -10 **(Clogston and Patri, 2011)**. We assume that applying the zeta potential to one of the studied lubricants was sufficient to assess the stability of the two lubricants.

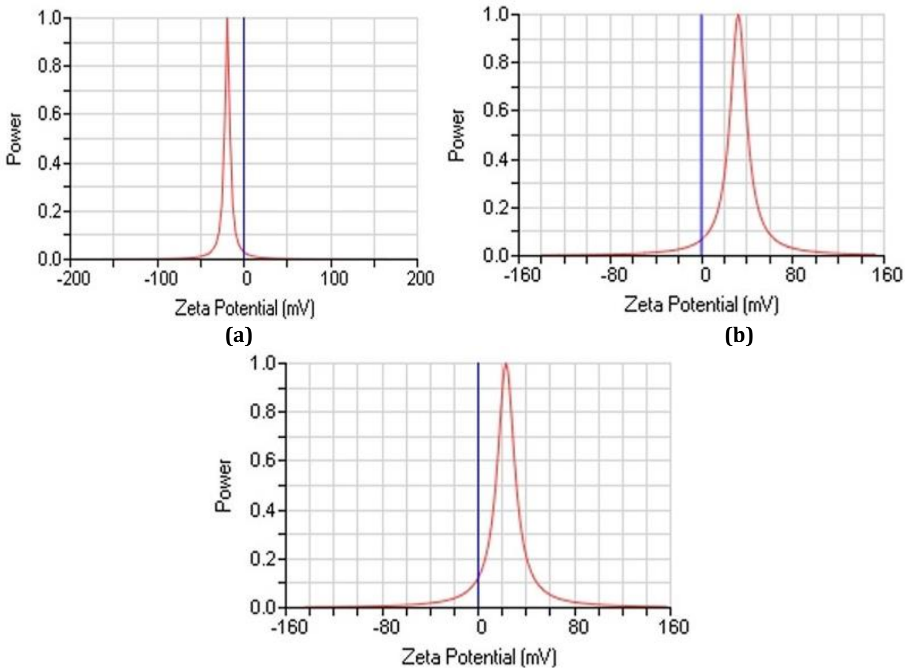
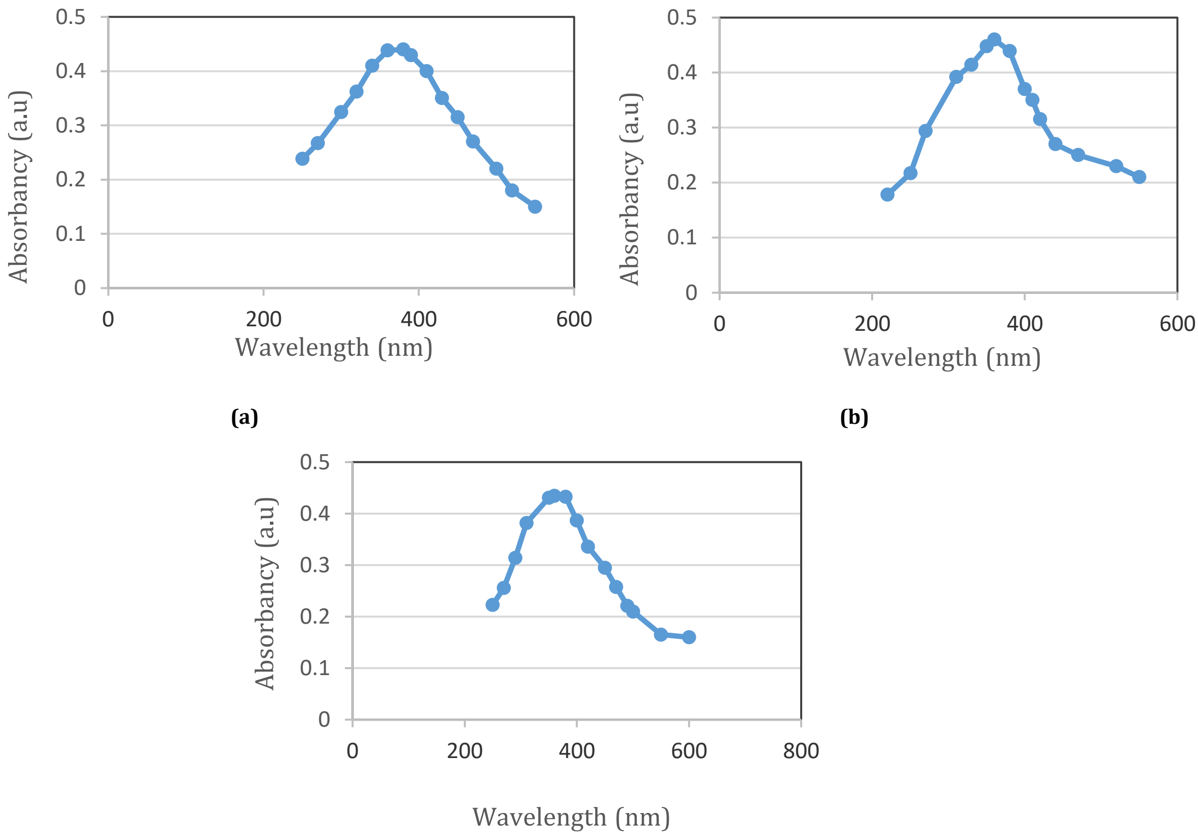


Figure 5. The Zeta-Potential Analysis in (10W-30) lubricant oil with (a) ZnO, (b) SiO_2 and (c) ZnO/SiO_2 hybrid NPs.

3.6 Nano Lubricant Stability Analysis (UV)

The stability of the (10W-30) nano-lubricating oil prepared with ZnO, SiO_2, and hybrid ZnO/SiO_2 was investigated using a UV-9200 spectrophotometer (Biotech Engineering Management Co., Ltd. UK). **Fig. 6** shows the absorption of the prepared base oil containing 1.0 wt.% zinc oxide, silicon dioxide, and zinc oxide with hybrid silicon dioxide. The highest wavelength (λmax) for all three assays is between 360 and 380 nm. From **Fig. 6 (a, b, and c)**, the nano-lubricating oil exhibits good stability over more than 1 week at room temperature **(Uppar et al., 2024)**.



(c)

Figure 6. UV Analysis for (a)ZnO, (b)SiO_2, and (c)hybrid (ZnO/SiO_2) NPs with (10W-30) oil.

3.7 Wear Scar Diameter Test (WSD)

To evaluate the wear scar diameter characteristics of (10W-30) lubricating oils with 1.0 wt.% for each (ZnO, SiO_2, and hybrid ZnO/SiO_2) NPs, tests were conducted in accordance with the ASTM D4172 standard and by (Koehler, New York, USA, S.N236) device. Each experimental run utilized a fresh set of steel balls to ensure accurate measurements. Under various loads, the lubricants were maintained at 75°C and subjected to a rotational speed of 1200 rpm of the device for a duration of 60 minutes. Following the procedure, the resulting wear scar diameters for the test balls were measured using microscopy; the oil containing SiO_2 NPs was found to be superior to the other nanolubricant oils, as shown in **Figs. 7 and 8 (Abhang et al., 2025; Yadav et al., 2018).**

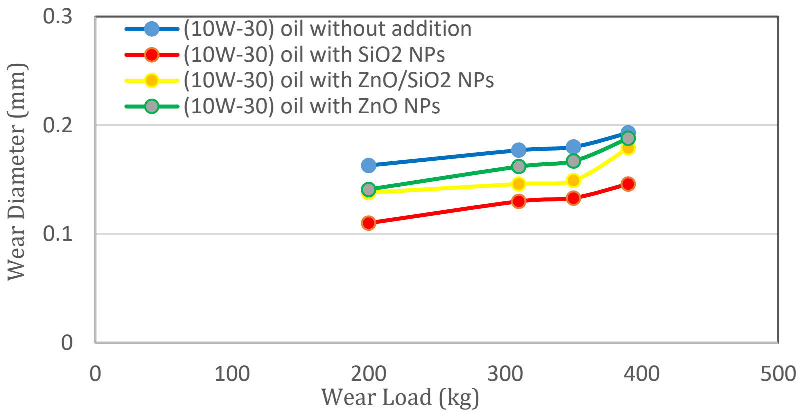


Figure 7. Wear scar diameter for ZnO, SiO_2, and hybrid (ZnO/SiO_2) NPs with (10W-30) oil.

Fig. 8 (a, b, c, d) shows the wear patterns that occurred on the balls inside (10W-30) nanolubricant oil under a load of (390 kg) at 75 °C and a speed of 1200 rpm for 60 minutes per ball, according to the type of nanoparticles they contained.

(a) without addition (b) ZnO (c) ZnO/SiO_2 (d) SiO_2

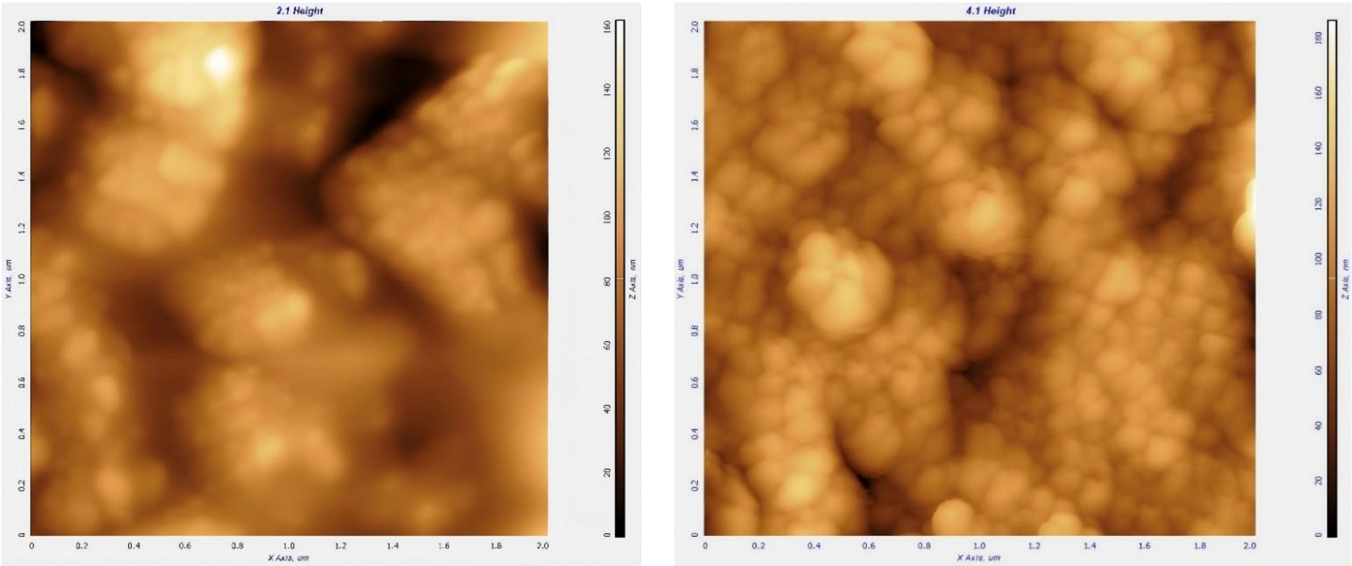
Figure 8. Wear scars of ball specimens at load (390kg) after 60 min. with (10W-30) oil.

3.8 Atomic Force Microscopy (AFM) of Nanoparticles

The surface morphology of the ZnO thin films is defined by a dense arrangement of individual grains. As observed across the scanned areas, the nanoparticles (NPs) do not remain isolated; instead, they exhibit a strong tendency to form larger clusters. This agglomeration, captured in **Fig. 9(a)**, is a typical result of the high surface energy characteristic of ZnO. While many particles retain a quasi-spherical geometry, others show more irregular shapes. The 3D perspective in **Fig. 10(a)** reveals a rugged landscape of sharp peaks and deep valleys, indicating substantial surface roughness **(Mariño et al., 2023; Ajeena et al., 2022; Clogston and Patri, 2011; Awad et al., 2022)**. A similar granular morphology is evident in the SiO_2 films, where closely packed NPs are prone to aggregational behavior consistent with high-surface-energy nanomaterials. As seen in **Fig. 9(b)**, these grains vary from spherical to irregular and consolidate into dense clusters. The 3D visualization in **Fig. 10(b)** confirms a highly corrugated and uneven topographic profile **(Desai et al., 2021; Mariño et al., 2021)**.

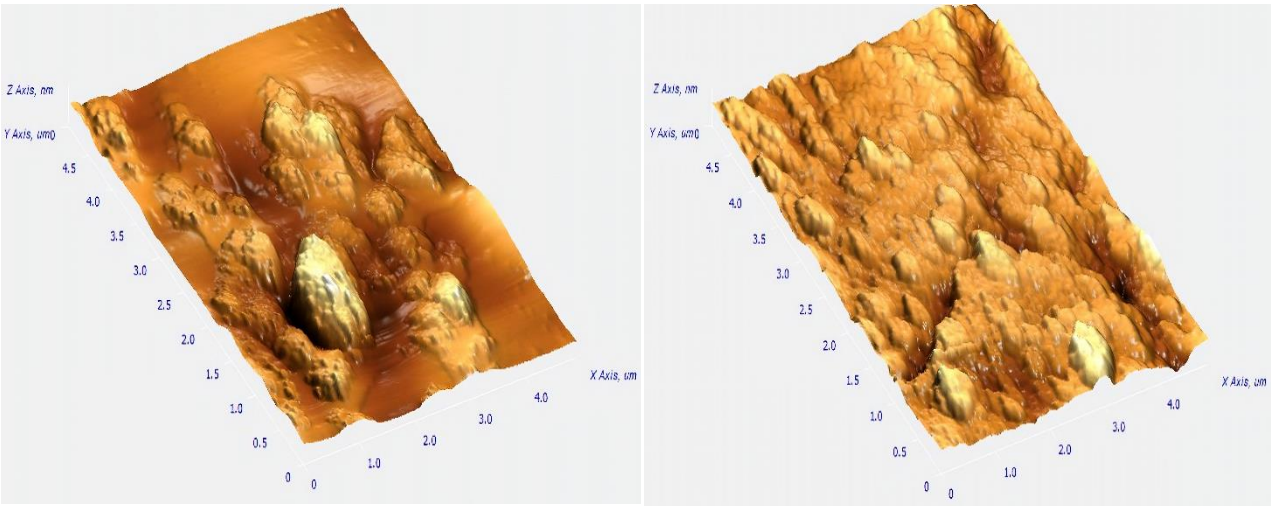
While the sample is polydisperse, the size distribution is notably concentrated at the lower end of the scale. **Fig. 11(a)** shows that the average diameter remains consistently below 40 nm, with the most frequent occurrences falling between 10 and 20 nm. Such a distribution indicates precise control over the nucleation phase during ZnO synthesis. Conversely, the SiO_2 sample displays a broader polydispersity, spanning a wider range of dimensions. Its distribution primarily peaks between 20 and 60 nm, with a central maximum near 40 nm.

Interestingly, the data in **Fig. 11(b)** highlights a dual-population trend, with significant counts at both the lower extremity and the 40 nm mid-range **(Sharif et al., 2023)**. A summary of the prepared NPs' properties is illustrated in **Table 2**.



(a) (b)

Figure 9. Two -dimensional AFM of (a) ZnO and (b) SiO_2 NPs.

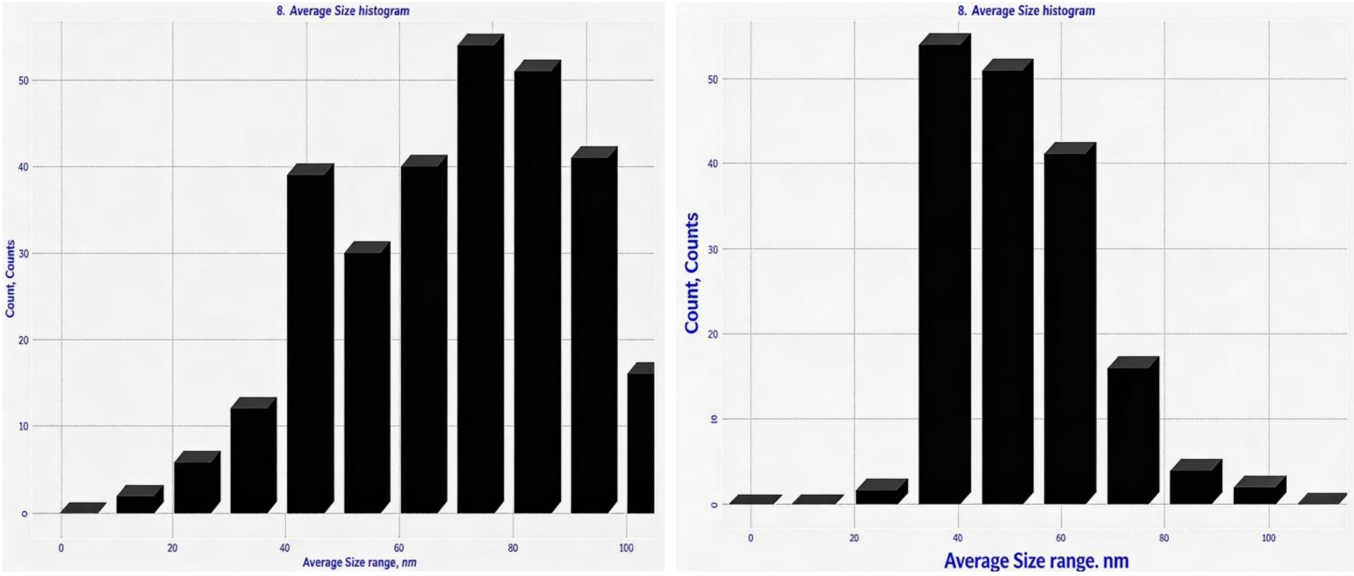


(a) (b)

Figure 10. Three -dimensional AFM of (a) ZnO and (b) SiO_2 NPs.

Table 2. Properties of the prepared zinc oxide and silicon dioxide nanoparticles.

Specifications	**ZnO**	**SiO_2**
Color	White	White
Crystal form	Sphere	Sphere
Purity (%)	99.9 >	98>
Particle Size (nm)	55-95	40-60
Surface area (m^2/g)	~65	160-200
Density (g/cm^3)	5.606	2.4

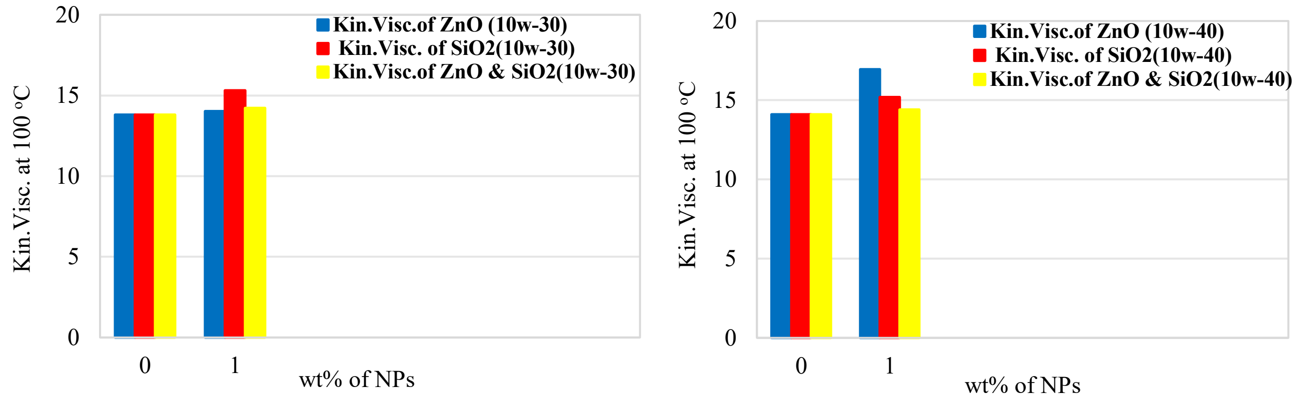


(a) (b)

Figure 11. The histogram of size distribution for (a) ZnO and (b) SiO_2 NPs.

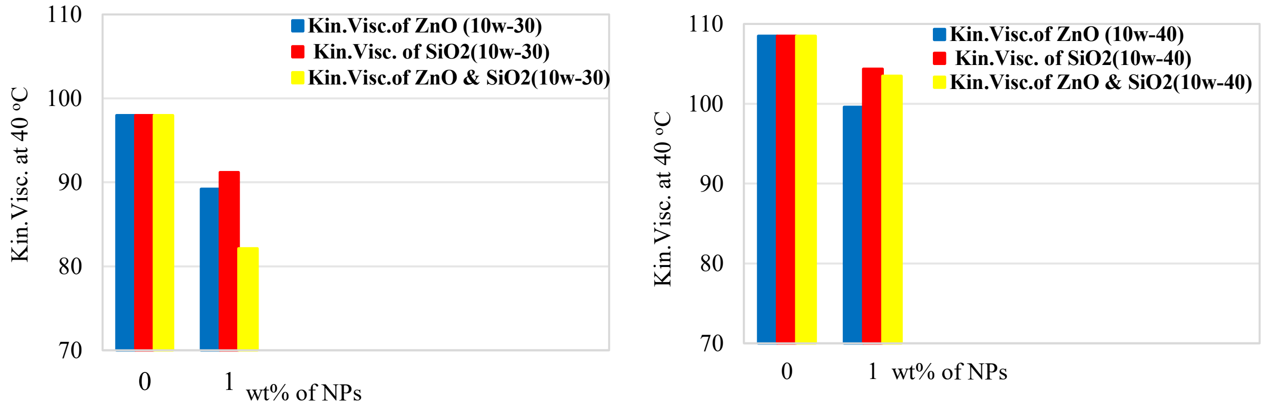
3.9 Effect of Nanoparticles on the Kinematic Viscosity and Viscosity Index of Nanolub ricant Oils

The kinematic viscosity and viscosity index of the nanoparticle lubricants were determined to use a capillary viscometer according to ASTM D445 standards. The measurements were performed on (10W-30) and (10W-40) engine oils without and with nanoparticles at a concentration of 1.0 wt.% and at two standard temperatures, 100°C and 40°C. The results are shown in **Fig. 12(a)**. A significant increase in the kinematic viscosity of the (10W-30) oil with SiO_2 additive, followed by the hybrids NPs, and then ZnO at 100°C. In **Fig. 12(b)**, the effect of ZnO and SiO_2 NPs was clear on the oil (10W-40) at 100°C. In **Fig.13**, no significant effect of nanomaterials on (10W-30) and (10W-40) oil was observed at 40°C. There is a clear relationship between the properties of the nanoparticles and the properties of the oil on one hand, and the kinematic viscosity of nano-lubricating oils at both temperatures on the other hand. ZnO nanoparticles showed the most effective enhancement for the oil (10W-40) due to their high hydrophobicity and density **(Mousavi et al., 2021; Kumar et al., 2021; Desai et al., 2021)**. As shown in **Fig. 14(b)**, the ZnO-based nano-lubricating oils achieved the highest viscosity index for the oil (10W-40), which was 122.5, while **Fig. 14(a)** for (10W-30), the viscosity index was 120.1. These values exceeded the values for SiO_2 nano-lubricants, in **Fig. 14(b),** which reached 119.3 for (10W-40) oil and in **Fig. 14(a)** at 121.8 for (10W-30) oil. **Fig. 14(a)** also showed that the SiO_2/ZnO hybrid nano-lubricants had an improved viscosity index of 122 for (10W-30) oil and in **Fig. 14(b)**119 for (10W-40) oil. These results confirm that the inclusion of nanoparticles can effectively enhance the viscosity index of both (10W-30) and (10W-40) engine oils **(Mariño et al., 2022; Sharif et al., 2023)**.



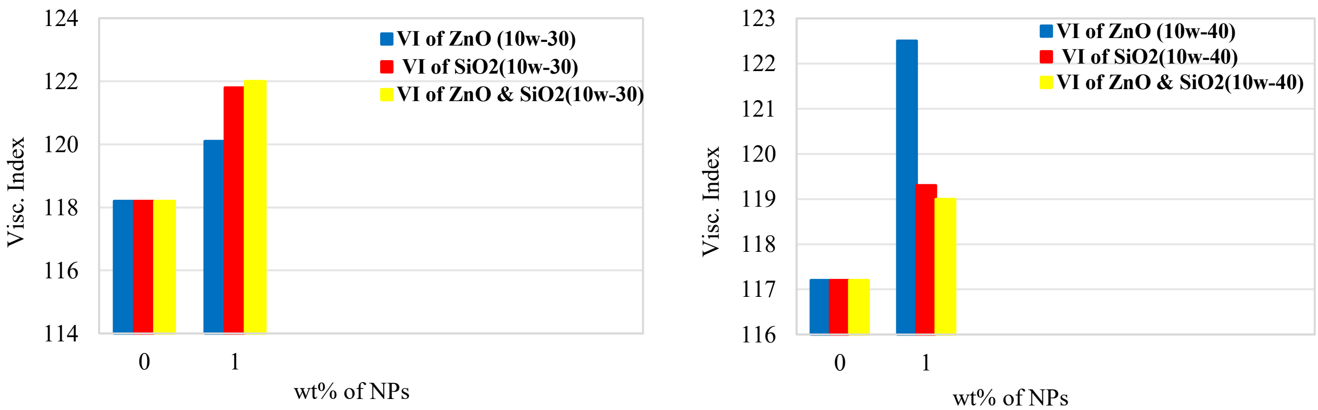
(a) **(b)**

Figure 12. Effect of adding ZnO, SiO_2, and ZnO/SiO_2 (hybrid) NPs on kinematic viscosity at 100°C of (a) (10W-30) and (b) (10W-40) oil.



(a) **(b)**

Figure 13. Effect of adding ZnO, SiO_2, and ZnO/SiO_2 (hybrid)NPs on kinematic viscosity at 40°C of (a) (10W-30) and (b) (10W-40) oil.

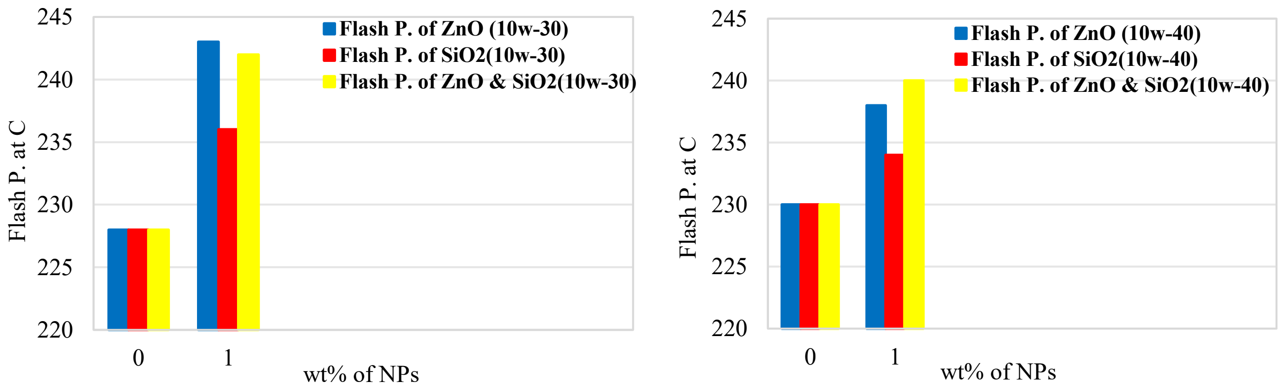


(a) **(b)**

Figure 14. Effect of adding ZnO, SiO_2 and ZnO/SiO_2 (hybrid)NPs on the viscosity index of (a) (10W-30) and (b)(10W-40) oil.

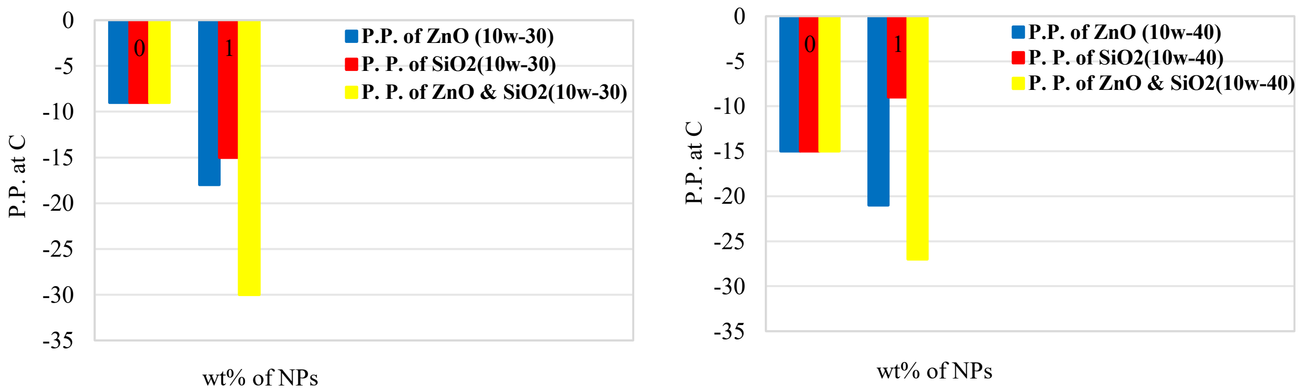
3.10 Flash Point and Pour Point of Nano-Lubricating Oil

The flash point is a critical property of lubricating oils, determining their ability to ignite under varying engine operating conditions, and it was evaluated according to the ASTM D-92 standard. As illustrated in **Fig. 15**, the flash point of the commercial oils (10W-30) and (10W-40) increased progressively with nanoparticle additives, demonstrating an enhancement in nano-lubricant quality and its performance during engine operation at high temperatures **(Kumar et al., 2021; Awad et al., 2022).** This keeps the oil from ignition during operation. In addition, the lubricant must have a suitable viscosity to maintain good circulation into the engine during start-up. Thus, reducing wear of internal moving parts. The effect of ZnO and SiO_2 nanoparticles on the pour point of the lubricating oils was tested by the ASTM-D97 method, as shown on **Fig. 16**. In this study, the pour points of the nano lubricants were found to be between −15 °C and −30°C with a drop in pour points between 6 °C and 9 °C. The drops in pour points keep a smooth flow of nano-lubricant at low temperatures. This effect was dependent on both the lubricant type and the additives incorporated. The most significant improvements were observed for the hybrid ZnO and SiO_2 nanoparticles aligned with **(Mousavi et al., 2020; Kumar et al., 2021)**.



(a) **(b)**

Figure 15. Effect of added ZnO, SiO_2 and ZnO/SiO_2 (hybrid)NPs on the flash point (a) (10W-30) and (b) (10W-40) oil.



(a) **(b)**

Figure 16. Effect of added ZnO, SiO_2 and ZnO/SiO_2 (hybrid)NPs on the pour point (a) (10W-30) and (b) (10W-40) oil.

Table 3. Comparison of the results from the present study with the literature.

Research	K.V. at 100C̊ (cSt)	K.V. at 40 C̊ (cSt)	VI	Flash point	Pour point
(Fahad and Abdul Majeed, 2022) at 1.0wt.% of TiO_2, CuO with base oil SAE-40	3.652	16.08	107	220	-18
(Kumar et al., 2021) at 0.5 wt% of ZnO with polyester oil	----	14.9	158	265	-24.8
(Awad et al., 2022) at 1.0wt% of SiO_2 with SAE-60 oil	49.23	91.75	----	253	-6
(**Elagouz et al., 2019)** at 0.8wt% of ZnO with (10W-40) oil	9.9	54.1	168	----	----
(Hadi and Almilly, 2026) at 1.0wt.% of ZnO with (10W-30)	8.9	46.83	121.5	248	-39

4. CONCLUSIONS

The present study has reinforced the idea that nano additives can enhance the rheological properties of commercial lubricants, not only the base lubricants. Zinc oxide (ZnO) and silicon dioxide (SiO_2) nanoparticles were successfully achieved by the sol–gel procedure, indicating precise control over the purity, morphology, and surface area. When nanoparticles were incorporated into commercial lubricant oil, they showed noticeable elevation in kinematic viscosity at 40°C, while showing a clearer rise at 100°C. The Viscosity Index (VI) of (10W-30) oil increased 1.6% and 4.5% for (10W-40) oil with ZnO, and VI of (10W-30) oil increased 3.05% and 1.8% of (10W-40) oil, with SiO_2, and VI increased 3.04% of (10W-30) oil and 4.35% for (10W-40) oil with hybrid ZnO/SiO_2 NPs. The results and tests for commercial oils explain ZnO to be the most effective nano-additive for enhancing thermal-viscosity properties and stability of commercial oils. Thermal performance was further supported as the flash points of both lubricant grades surpassed those of the samples without nano additives. The study also showed that synergistic hybrid nano additives boosted the rheological properties of nano lubricants with a blend of 0.75 wt.% ZnO and 0.25 wt.% SiO_2, which yielded the most significant VI values. These findings suggest that nano-additives can effectively be a solution for the enhancement of the physical properties of commercial lubricants. Thus, upgrading the overall operational efficiency of the engines. Also, a clear correlation between nanomaterial density and oil grade was noticed; the heavier ZnO nanoparticles were most compatible with the (10W-40) heavy-duty oil, while the lighter SiO_2 nanoparticles demonstrated superior performance in the (10W-30) light-duty oil.

Credit Authorship Contribution Statement

Haider Ahmed: Writing original draft, Validation, Software, Methodology. Raghad Fareed: Supervision, editing, and reviewing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal rela tionships that could have appeared to influence the work reported in this paper.

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تحسين الخصائص الريولوجية لزيوت التزييت التجارية عبر أكاسيد الجسيمات النانوية المختلفة

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الخلاصة

يتناول هذا البحث تقييم التأثيرات الفردية والتآزرية لجزيئات أكسيد الزنك (ZnO) وثاني أكسيد السيليكون (SiO_2) النانوية عند دمجها في الزيوت التجارية (10w-30) و(10w-40) لتحسين أدائها. تم تصنيع المواد النانوية عبر تقنية سول–جيل مما أدى إلى إنتاج جزيئات عالية النقاء (99.9% لـZnO و98.0% لـ SiO_2) بمعلمات محددة جيدًا. كانت أقطار ومساحات سطح جزيئات الـ ZnO و SiO_2 55–95 نانومتر و40–60 نانومتر و65 م^2\غم و160–200 م^2\غم على التوالي. ومن حيث محاولة الوصول إلى أفضل تركيز تم استخدام تركيز 1.0% بالوزن لكل مادة نانوية (بعد اختبار النسب المختلفة). تم استخدام إجراء التحضير على مرحلتين للحصول على مادة تزييت نانوية مستقرة في درجة حرارة الغرفة. أولاً، تم استخدام المحرض المغناطيسي مع إضافة حمض الأوليك. ثانيا"، تم استخدام خلاط عالي السرعة. وأكدت النتائج وجود تحسن ملحوظ في الخواص الفيزيائية لزيوت التزييت النانوية. تم تسجيل تحسن في مؤشر اللزوجة من 118.2 إلى 120.1 و121.8 لـZnO و SiO_2 مع زيت (10w-30) على التوالي. بالنسبة لـ 10w-40/ZnO و10w-40/SiO_2، ارتفع مؤشر اللزوجة من 117.2 إلى 122.5 و119.3 على التوالي. بالنسبة للتركيبة الهجينة، تم استخدام مزيج من 0.75% بالوزن ZnO و 0.25% بالوزن SiO_2 (أفضل تركيز هجين حصل على 1.0% بعد تجربة نسب مختلفة) مع درجتي الزيت 10W-30 و10W-40 ، وكان مؤشر اللزوجة 122 و119 على التوالي. تم التوصل إلى أن الإضافات النانوية يمكن أن تكون الحل لأوجه القصور في أداء الزيوت التجارية من خلال رفع مؤشر اللزوجة ونقطة الوميض وتقليل نقطة الانسكاب.

الكلمات المفتاحية: زيوت تزييت تجارية، أوكسيد الزنك وثاني أوكسيد السيليكون النانوية، نقطة الصب، نقطة الوميض، مؤشر اللزوجة.