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EFFECT OF NANOPARTICLES ON ENHANCING THE VISCOSITY OF LUBRICANT OIL

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ABSTRACT

Lubricating oils play a crucial role in reducing friction in engines and other moving machine parts. In this study, nano-additives (ZnO and SiO_2) were successfully prepared using a sol-gel method, yielding nanomaterials with specific measured values such as the purity, diameter, and surface area, and blended with commercial 5w-20 lubricating oil. Additionally, a mixture of these two nanomaterials was used together in the commercial oil. The nanomaterials were blended at different ratios (0.1%, 0.3%, 0.5%, 0.7%, and 1.0 % wt) with the lubricating oil using two steps. First, a magnetic stirrer with the presence of oleic acid as a surfactant, and second, with a high-speed homogenizer electric mixer. The physical properties of the nano-oil, such as viscosity index, were enhanced from 117 to 121.5 with ZnO and from 117 to 119.5 with SiO_2. The enhancement was from 117 to 120.2 when the two types of nanomaterials were used together.

KEYWORDS

Commercial nano-lubricants, ZnO and SiO_2 Nanomaterials,sol-gel nanoparticles, Viscosity Index.

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1. INTRODUCTION

Lubricating oil is essential for reducing friction and wear among an engine's moving components, thereby boosting its efficiency and prolonging its operational lifespan. A lubricant's effectiveness is largely dependent on its viscosity (Cai et al., 2013). The viscosity is a characteristic that influences the thickness of the protective film and its ability to maintain a physical barrier between surfaces under various working conditions (Gulzar et al., 2016). New methods are emerging to mitigate the adverse environmental effects of vehicles; for example, two key strategies are employed: the development of new, eco-friendly materials and the regulation of fuel combustion. However, conventional lubricants may prove inadequate in harsh environments, such as those with high temperatures and pressures. These conditions can cause the oil's viscosity to drop, leading to increased wear and wasted energy. An innovative approach to address these shortcomings involves incorporating nanoparticles into base oils. Nano-additive materials such as zinc oxide (ZnO), titanium dioxide (TiO_2), silicon dioxide (SiO_2), and aluminum oxide (Al_2O_3) can improve the rheological and tribological characteristics of lubricants (Korada and Hamid, 2014; Ali and Salam, 2020, Zeiny et al., 2025). The use of these nano-lubricants can lead to better thermal stability, an increase in viscosity and viscosity index, and a reduction in both wear and friction. These improvements are attributed to the nanoparticles' exceptional their unique properties and a high surface area relative to their volume, interactions with the molecules of the base oil (Mohan et al., 2014). Nanoparticles are materials and powders that have been optimized to function at the nanoscale, defined as 1 to 100 nanometers (Hadi and Abd al-Hussain, 2018; Esfe et al., 2019). The method by which nanoparticles improve viscosity is complex and involves several factors. This process includes physical interactions like the clumping of particles, the bonding between the oil and nanoparticle surfaces, and alterations to the oil's internal structure. The effectiveness of these nanoparticles is also heavily influenced by their specific type, shape, concentration, and how their surfaces are modified (Peña-Parás et al.,2015). Nanoparticle additives, when used in low concentrations (typically1.0 % by weight), have been shown to significantly boost a lubricant's dynamic and kinematic viscosities and viscosity index (Dhaef Alikhan et al., 2025). This translates to a more stable and effective lubricant across a range of operating conditions. When NPs are present in the fluid at higher concentrations, they can cause sedimentation due to their limited stability within the liquid. However, traditional lubricants often fail to maintain their optimal viscosity. Despite significant advancements, the scientific community still faces challenges in understanding the mechanisms by which nanoparticles affect viscosity. Key issues include particle agglomeration, long-term stability, dispersion methods, and the optimum concentration needed for desired viscosity improvements without causing sedimentation or system blockage (Demas et al.,2012). This phenomenon has been well-documented in research, as evidenced by studies from Ghaednia (2014), Bakunin et al.(2004). Lubricants are essential for meeting the high demands of internal combustion engines, requiring both strong lubricity and extended longevity (Jatti and Singh, 2015; Amiril et al., 2017). A study by Kumar et al. (2021) investigated the effect of zinc oxide (ZnO) nanoparticles on the thermophysical and tribological properties of polyolester (POE) oil. The research's objective was to evaluate the potential of using this mixture as a nano-lubricant in refrigeration compressors, focusing on its eco-friendly characteristics. The study involved adding ZnO NPs to the POE oil in mass fractions ranging from 0.1% to 0.5%. The properties of the resulting nano-lubricant were then assessed at various temperatures: 0 °C, 20 °C, 30 °C, 40 °C, and 60 °C.Fahad and Abdul Majeed (2022) recorded the highest viscosity index for the 40-stock base oil, which was observed at a concentration of 0.8 wt.% of the modified TiO_2-CuO NPs, reaching a value of 108.5. This indicates improved viscosity performance over a range of temperatures. The flash point of the base oil increased with higher concentrations of the modified NPs. The maximum value recorded was 220 °C. The pour point of the nano-lubricating oil decreased from -12 °C (for the original base oil) to -15 °C when 0.8 wt.% of the modified TiO_2-CuO NPs were added. A study by Sankar and Duraivelu (2023) examined the changes in thermophysical properties of SN500 lubricant oil. They blended the oil with three nano-additives: silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and titanium dioxide (TiO_2). The research utilized fuzzy logic to predict and improve the lubricant's characteristics. The goal was to enhance key properties like wear, coefficient of friction (CoF), thermal conductivity, density, flash point, and fire point. The nano-additives were mixed with the SN500 base oil in various proportions to determine their effect on the overall lubricant performance. This research aims to present a study of the influence of NPs, ZnO, SiO_2, and a blend of them in different concentrations, on a commercial lubricant to improve its specifications for which it is made.

2. EXPERIMENTAL WORK

2.1. Materials

Commercial SAE 5W-20 engine oil (the specifications are listed in Table 1), Zinc acetate dihydrate (≥ 99.5% purity, BDH Chemicals Ltd. Poole England), Sodium hydroxide (≥ 98% purity, from Alpha Chemika. India), Ethanol (99.8% purity, BDH For Chemicals from England), Methanol (99.8% purity, BDH For Chemicals from England), Acetic Acid (99.5% purity, BDH Chemicals Ltd. Poole England), tetraethyl orthosilicate (TEOS) (98% purity, Sigma Aldrich USA), distilled water.

Table 1 Specifications of SAE 5W-20 Commercial Oil

No.	Specifications	Amount
1	Density at 15 °C (kg/m^3)	857
2	Flash Point (°C)	232
3	Pour Point (°C)	-36
4	Viscosity Index	117
5	Kin. Viscosity at 100°C (cSt)	8.5
6	Kin. Viscosity at 40°C (cSt)	54.54

2.2. Equipment

Hotplate Magnetic stirrer (Alfa, HS-860, Iran), Homogenizer (OS40-Pro Darwell digital Stirrer lab, China), Specific gravity Hydrometer (Alla 0.8-0.9 gm/cm^3, France).

2.3. Procedure

2.3.1. Synthesis of nanoparticles

A zinc oxide (ZnO) nanostructure was synthesized using the sol-gel method by dissolving 2 grams of zinc acetate dehydrate (≥ 99% purity) in 15 ml of distilled water. Separately, 8 grams of sodium hydroxide (≥ 98% purity) was added to 10 ml of distilled water. Both solutions were stirred for approximately five minutes. Next, 100 ml of ethanol was gradually titrated into the mixture containing both solutions. The formation of a white precipitate confirmed that the reaction was complete (Hasnidawani et al., 2015) as shown in Fig. 1. Silica Dioxide (SiO_2) was prepared from 20 ml of methanol (CH_3OH) dissolved in 2.3 ml of acetic acid (CH_3COOH) and stirred for 5 minutes at room temperature. After that 1.5ml of TEOS (Si was added drop-wise. After 90 minutes of stirring, a homogeneous transparent solution was appeared, and after drying, a white powder was obtained, following Saravanan and Dubey, 2020) as shown in Fig.1.

Fig. 1. Preparation of ZnO and SiO_2 NPs

2.3.2. Preparation of nano-lubricating oil

To prepare nano-lubricating oil, ZnO and SiO_2 were directly added to 100 ml of commercial SAE 5W-20 engine oil. The nano-lubricating oil was tested at varying weight percentages: 0.1%, 0.3%, 0.5%, 0.7%, and 1.0 % wt.It is homogeneously distributed and not precipitated. ZnO NPs showed 5-6 days stabilitywhich is asuitable period for use. The concentration range (0.1-1.0 wt%) was chosen for its suitability to avoid agglomeration and reach to cost effective amount. The goal was to create a stable and homogeneous suspension of nanoparticles within the oil by adding a suitable surfactant (oleic acid) while a magnetic stirrer was used for 2hr stirring at ambient temperature. After that, a homogenizer was used for another 2 hr at 2000 rpm speed to prevent NPs agglomeration as shown in Fig. 2. The nano-lubricants were kept at room temperature after preparation without noticing any sedimentation.

Fig. 2. Dispersion of NPs into lubricating oil by an electrical high-speed homogenizer

Fig. 3 shows the general steps of the experimental work procedure.

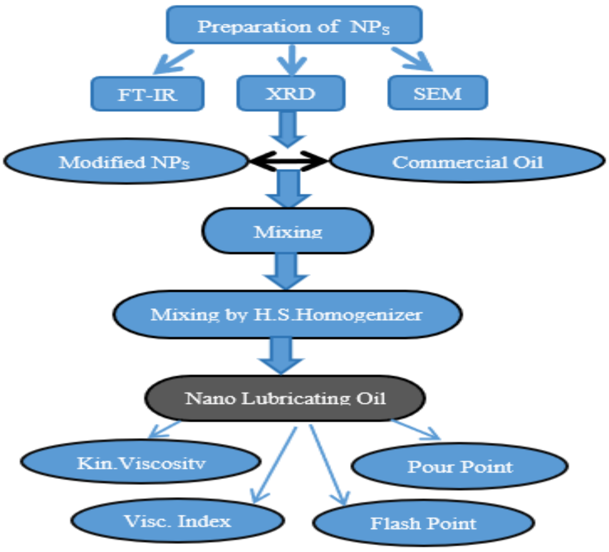

Fig. 3. The sequence of experimental steps diagram

3. RESULTS AND DISCUSSION

3.1. Energy dispersive x-ray spectroscopy (EDS)

The EDS spectrum confirms the elemental composition of the nanomaterials. The presence of only these two elements, zinc and oxygen, and their corresponding peaks strongly indicates that the chemical composition of the nanomaterial is (ZnO). The quantitative results show that oxygen has an atomic percentage of 86.59%, and zinc has an atomic percentage of 13.41%. In terms of weight, the sample contains 61.25% oxygen and 38.75% zinc. The automatic identification results corroborate these findings by showing strong peaks for oxygen (Ka1 line at 0.535 keV) and zinc (Ka1 line at 1.025 keV) (Kalyani et al.,2015) as shown in Fig. 4.

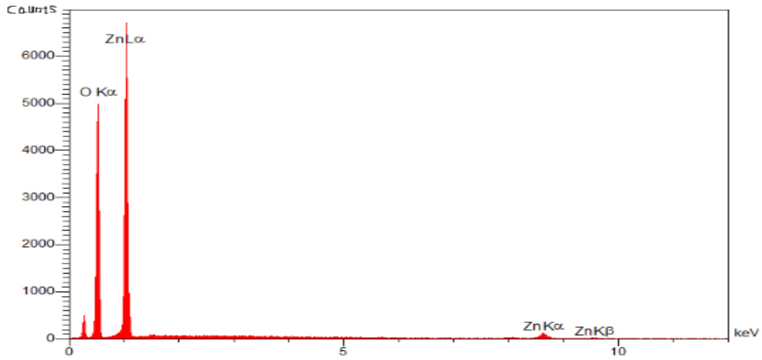

Fig. 4. The (EDS) analytical spectrum of ZnO

The report for SiO_2 NPs provides conclusive evidence that the sample is primarily composed of silicon and oxygen. The quantitative results show that the atomic percentage of oxygen is 47.68%, and the atomic percentage of silicon is 52.32%. The automatic identification results support these findings by showing a very strong silicon peak (Ortega et al., 2022) (Ka1 line at 1.765 keV) and a significant oxygen peak (Ka1 line at 0.545 keV) that shown in Fig. 5.

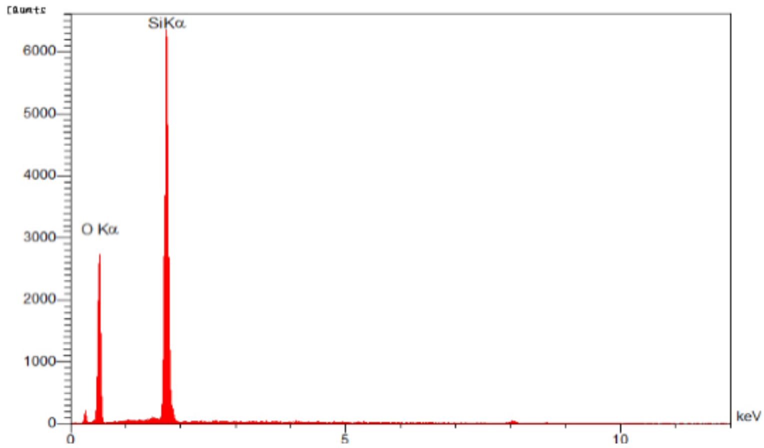

Fig. 5. The (EDS) analytical spectrum of SiO_2

3.2. FT-IR analysis of nanoparticles.

The FTIR spectrum of the ZnO NPs sample Fig. 6 exhibited two prominent peaks: an absorption band at 3410 cm−1, which is attributed to the stretching vibrations of the O-H group, indicating the presence of hydroxyl groups; and a vibration band at 468 cm−1, corresponding to the stretching vibration of the zincite (Zn-O) structure. Peaks observed at wavenumbers below 1000 cm^{-1} in this region are often associated with the vibrations of metal-oxygen bonds. The peaks at 879.54 cm^{-1}, 690.52 cm^{-1}, 522.71 cm^{-1}, 484.13 cm^{-1}, and 430.13 cm^{-1} are all characteristic of the presence of Zn-O stretching vibrations, confirming the formation of the zinc oxide lattice. The broadness and number of these peaks are typical for a powdered sample, as they are influenced by particle size, shape, and crystallinity (Hernaiz et al., 2023). Fig. 7 shows the FTIR spectrum for the SiO_2 sample, which displays several distinct peaks, each corresponding to specific molecular vibrations.1080.14 cm^{-1} and 1180.44 cm^{-1}. These are the most prominent peaks and are characteristic of the asymmetric stretching vibrations of Si-O-Si bonds provide evidence for the formation of the silicon dioxide network.

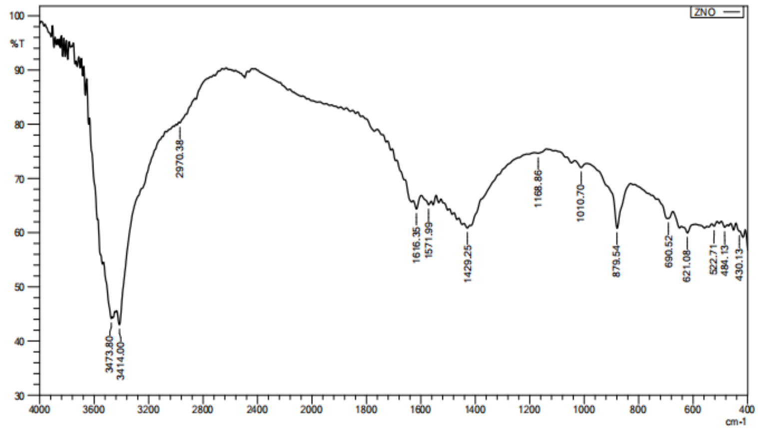

Fig. 6. Fourier transform infrared (FT-IR) analysis of ZnO

The material's main component. 948.98 cm^{-1}. This peak is often assigned to the stretching vibrations of Si-O bonds in silanol groups (Si-OH), which are hydroxyl groups directly bonded to silicon atoms on the nanoparticle surface. 798.53 cm^{-1} and 570.93 cm^{-1}, the peaks of the symmetric stretching vibrations of the Si-O-Si bonds confirm the presence of the SiO_2 framework. Additionally, a peak at 459.06 cm−1 is attributed to the bending vibrations of these same bonds. The existence of silanol groups (Si-OH) and adsorbed hydroxyl groups (O-H) is a key chemical property. This interaction can help disperse the nanoparticles uniformly within the lubricant, which is essential for stable performance.

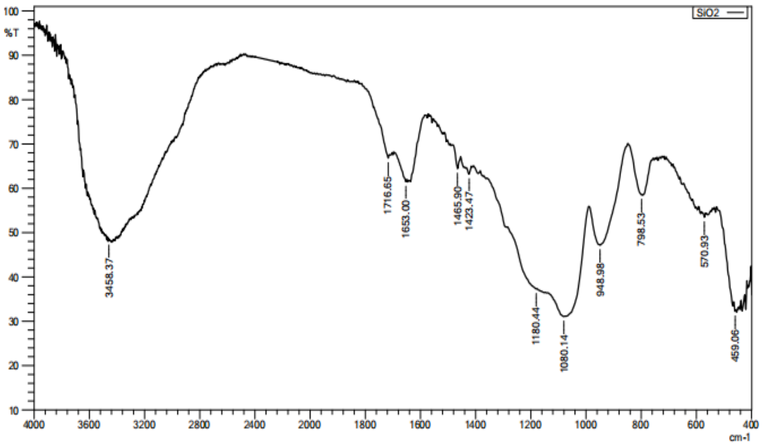

Fig. 7. Fourier transform Infrared (FT-IR) analysis of SiO_2

3.3. Characterization of NPs using FE-SEM

The morphology of nanoparticles was examined using scanning electron microscopy (SEM). There is regularity in the polydispersity distribution, indicating good sol-gel. In Fig. 8, the images illustrate the morphology of ZnO. Roughness of the structure that is not completely smooth, which has important properties such as increased surface area, useful in small and electronic applications. Surface density for the compact and interlocking structures shows that there is a high density of zinc oxide, which enhances chemical reactivity and absorption (Mousavi et al., 2018,Yasir. ,et al 2023).

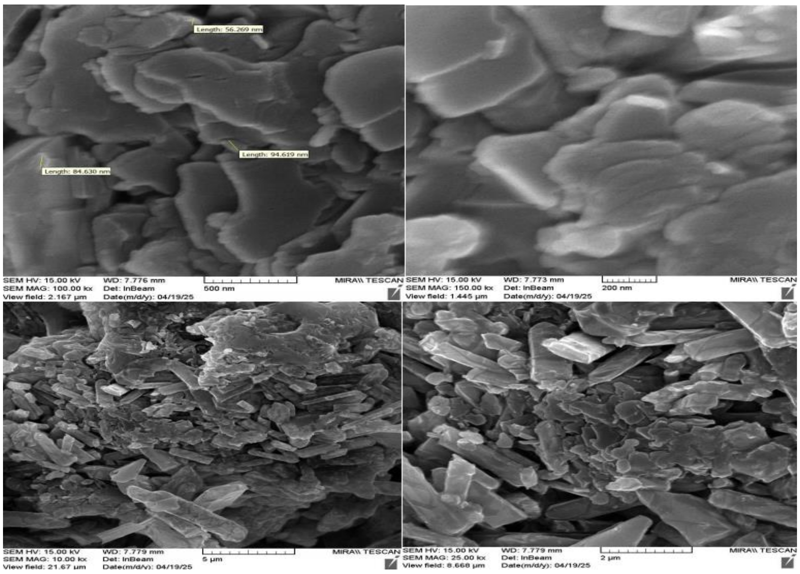

Fig. 8. FE-SEM of ZnO NPs

Surface morphology and structure of SiO_2 appear in the image to have a nearly uniform distribution of particles, with some porosity or nanostructures. Silicon dioxide is often amorphous, but after drying and heat-treated, fine crystalline structures developed. The grains appear to be closely spaced, indicating relatively uniform fabrication or deposition. In Fig. 9 the images illustrate the morphology of SiO_2. The absence of cracks or obvious impurities indicates high-quality processing or manufacturing.

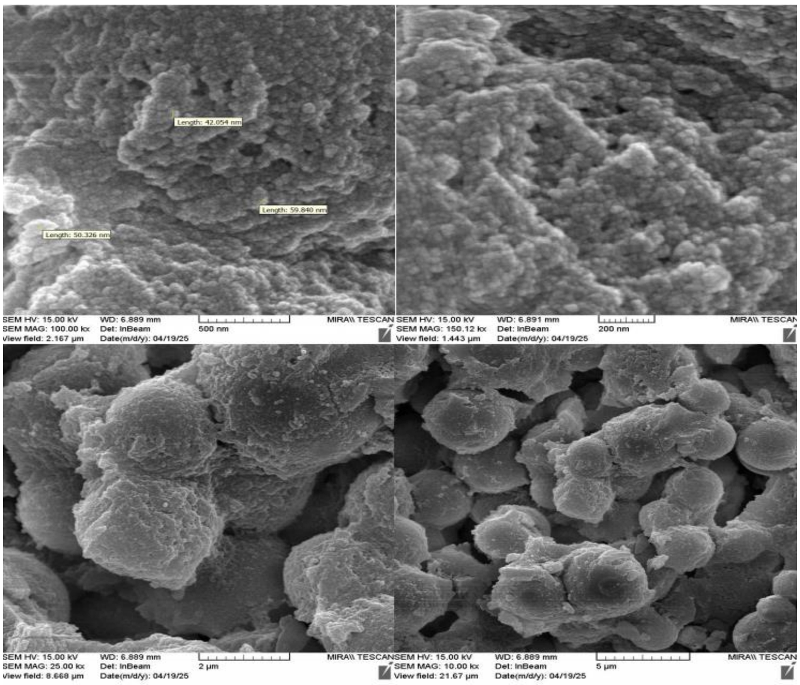

Fig. 9. FE-SEM of SiO_2 NPs

3.4. X-Ray diffraction (XRD) characterization of NPs

The peaks that are visible in the X-ray diffraction (XRD) pattern displayed characteristics of ZnO NPs. The sharp, well-defined peaks indicate that the synthesized material is crystalline and has a high degree of order, which confirms the successful formation of the intended material. The narrow and sharp nature of the diffraction peaks suggests that the synthesized ZnO NPs have a relatively large crystallite size and high crystallinity. The main diffraction peaks, such as those corresponding to the (100), (101), (102), and (110) planes, are clearly visible. The absence of any extraneous peaks confirms the high purity of the synthesized ZnO NPs with no detectable crystalline impurities. This is a key factor that impacts the rheological properties and stability of the nano-lubricant (Mousavi et al., 2018). Purity is essential to prevent unwanted chemical reactions and ensure the nano-additive performs as expected without degrading the base oil. The structure provides the necessary mechanical strength and tribological properties for friction and wear reduction in engine lubricants. The high crystallinity is beneficial for maintaining structural integrity under the high shear and temperature conditions of an engine. The tribological and rheological enhancements observed in the nano-lubricant are directly attributed to these well-defined properties of the ZnO NPs, confirming their suitability as an effective additive for improving the viscosity index of engine oils. Fig. 10 shows X-ray diffraction of ZnO NPs (Yasir. ,et al 2023).

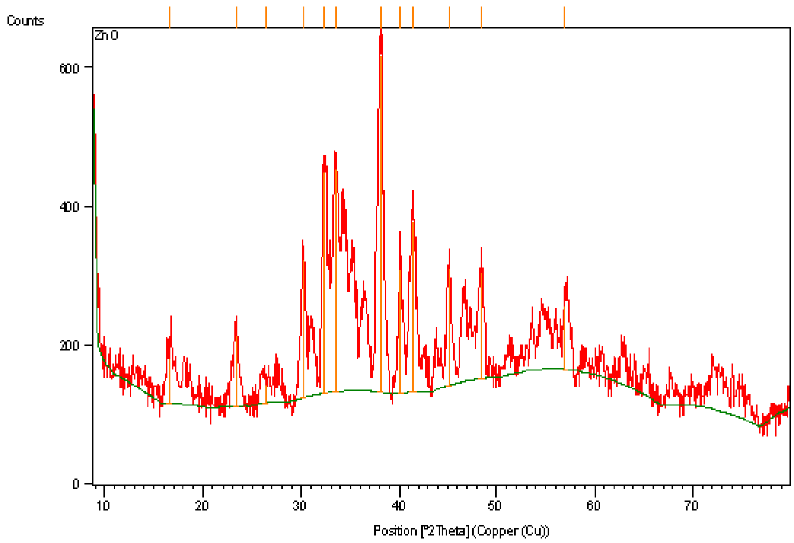

Fig. 10. XRD characterization of ZnO NPs

The XRD graph of the SiO_2 sample shows a single, broad, diffuse peak, with no distinct sharp peaks. This pattern is characteristic of amorphous materials, indicating the lack of long-range atomic order within the nanoparticles. Physical properties of the amorphous material mean that the atoms are arranged randomly rather than in a regular, repeating lattice. This property distinguishes it from crystalline forms of silica, such as quartz. The broadness of the peak is also an indicator of the nanoscale size of the particles. Amorphous silica nanoparticles are known for their high surface area-to-volume ratio, a physical property essential to their function. Chemical properties of the amorphous material of SiO_2 NPs give them high surface reactivity compared to their crystalline counterparts. These particles are characterized by high chemical stability and are not easily affected by chemical agents. This combination of high surface area and chemical inertness makes them suitable for use as additives in lubricating oils, as they can interact with oil molecules and surfaces without undergoing unwanted chemical reactions. Given the effect of nanoparticles on engine oil viscosity, these amorphous silicon dioxide (SiO_2) NPs contribute to improving the properties of lubricating oil by acting as solid lubricants or by forming a protective layer on engine parts. Their high surface area allows for strong interactions with oil molecules, which can improve viscosity and reduce friction and wear. Fig. 11 shows an X-ray diffraction analysis of silicon dioxide (SiO_2). Table 2 summarizes the main properties of the prepared ZnO and SiO_2 NPS.

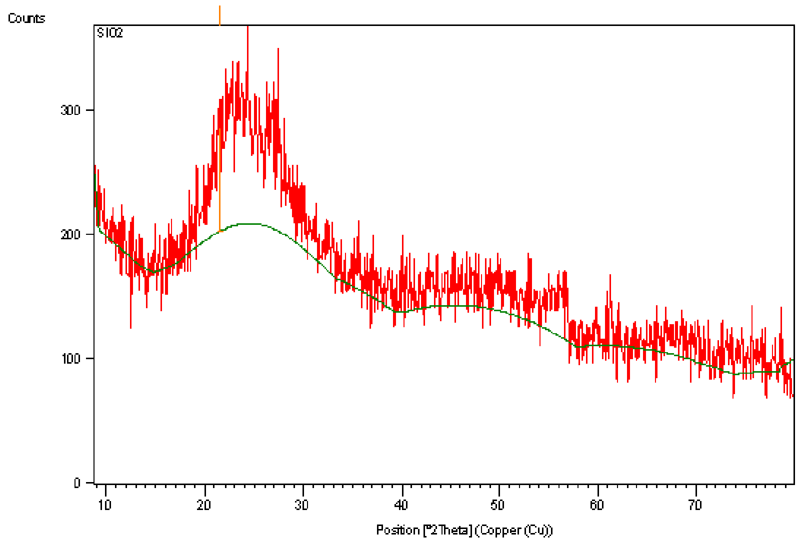

Fig. 11. XRD characterization of SiO_2 NPs

Table 2. The specifications of the prepared NPs: zinc oxide and silica

No.	Specifications	ZnO	SiO_2
1	Color	White	White
2	Crystal form	Sphere	Sphere
3	Purity (%)	99.9 >	98>
4	Particle Size (nm)	55-95	40-60
5	Surface area (m^2/g)	~65	160-600
6	Density (g/cm^3)	5.606	2.4

3.5. The Influence of the NPs on the kinematic viscosity and viscosity index of nano lubricants

The kinematic viscosity and viscosity index were measured according to ASTM D445 using a capillary viscometer. The kinematic viscosity of 5W-20 engine oil without and with NPs was tested at different concentrations (0.1, 0.3, 0.5, 0.7, and 1.0 wt%) at two characteristic temperatures, 40°C and 100°C. The results, as shown in Figs.12 and 13, indicate a direct relationship between the NPs concentration and the viscosity of the nano lubricants at both temperatures, especially for ZnO NPs. In Fig. 14. ZnO nano lubricants exhibited the highest viscosity index (121.5) at a concentration of 1.0 wt%, outperforming that of SiO_2 nano lubricants (119.5). Fig. 15 shows that the SiO_2/ZnO hybrid nano-lubricants exhibited an enhanced viscosity index (120.2) at (0.75 wt% ZnO and 0.25 wt% SiO_2) concentration. confirming that the incorporation of nanoparticles can effectively improve the viscosity index of 5W-20 lubricants (Abed et al., 2023, Revalina et al.,2024; Sharif et al.,2024).The Viscosity index enhancement is the most important property of the lubricating oil since it defines how the oil viscosity affected by the temperature . Therefore, any additional value of VI will enhance its use. The results showed that ZnO NPs were very effective to enhance the VI of the lubricating oi. Therefore, it is thought that increasing ZnO in the hybrid mixture will give better results than using equal amount of NPs (0.5 ZnO/0.5 SiO_2) or less (0.25ZnO/0.75SiO_2). Comparing the stability of ZnO NPs with the hybrid NPs (0.75ZnO/0.25SiO_2) shows that the agglomeration issue has been solved.

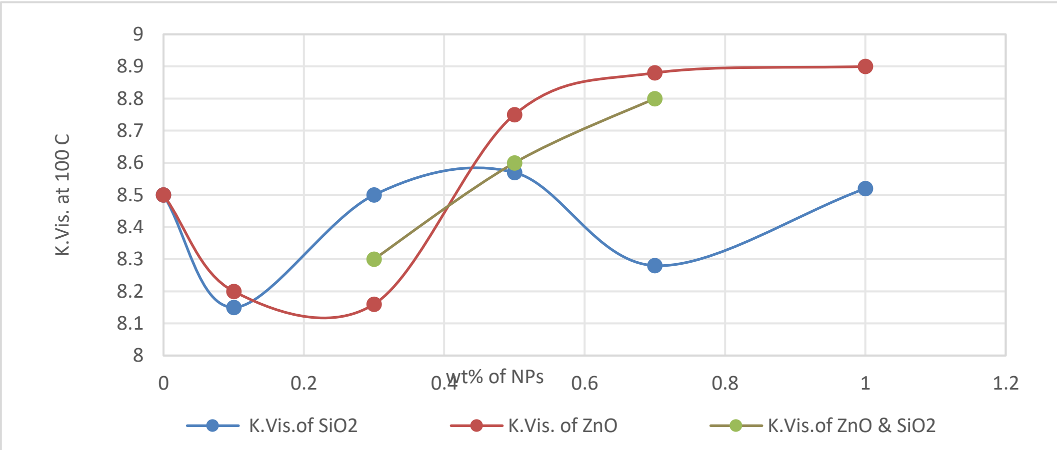

Fig. 12. Effect of adding ZnO and SiO_2 NPs on kinematic viscosity at 40 °C of commercial oil

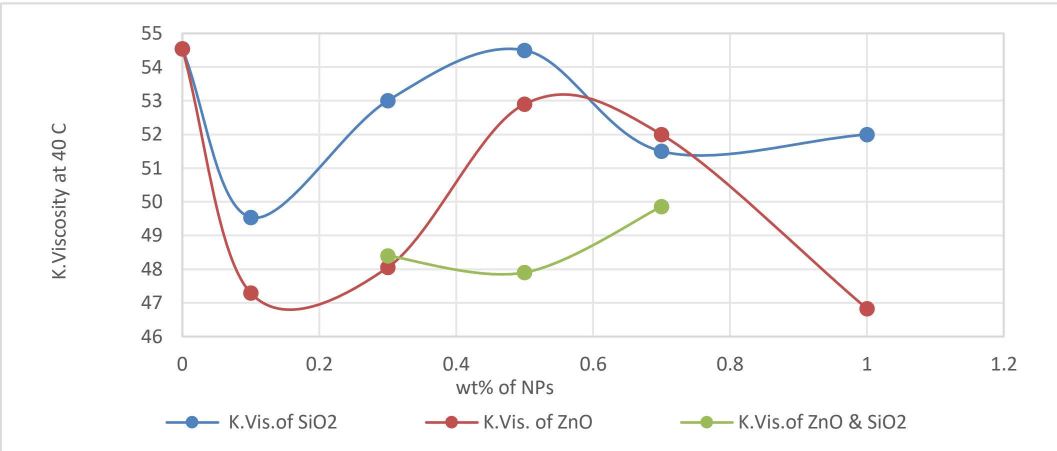

Fig. 13. Effect of adding ZnO and SiO_2 NPs on kinematic viscosity at 100 °C of commercial oil

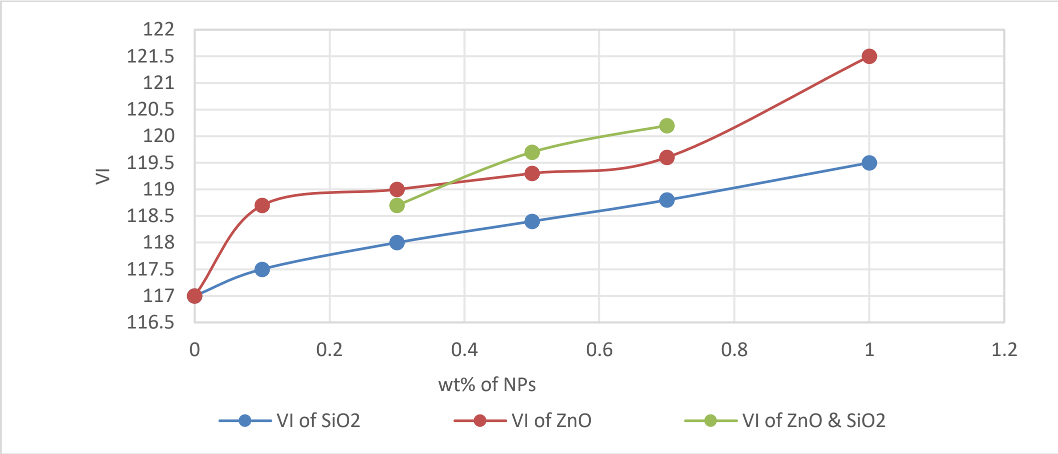

Fig. 14. Effect of adding ZnO and SiO_2 NPs on viscosity index of commercial oil

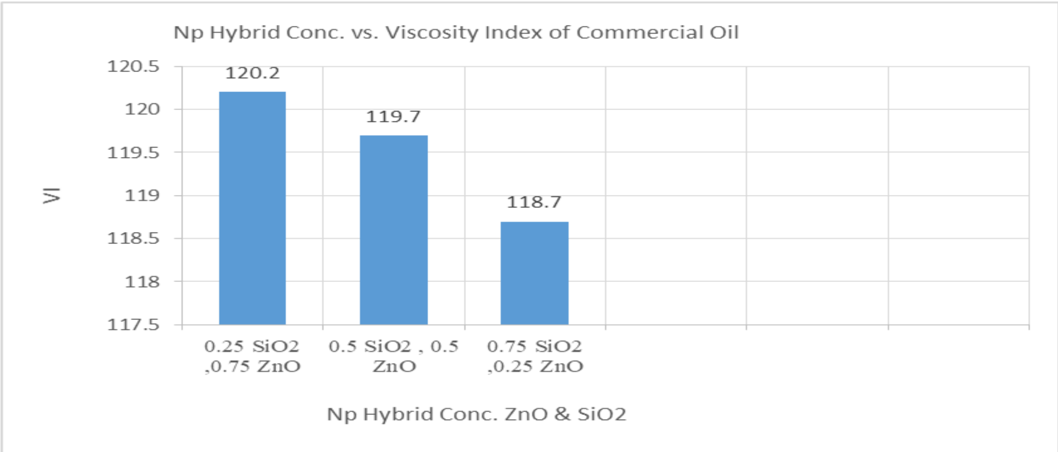

Fig. 15. Effect of adding ZnO/SiO_2 hybrid concentration together on viscosity index of commercial oil

3.6. Flashpoint and pour point of nano-lubricating oil

The flash point of a material is the lowest liquid temperature at which, under certain standardized conditions, a liquid gives off vapors.It is a property of lubricating oils that enables them to combust inside engines under various operating conditions and is measured by the ASTM D92 method. Fig. 16 shows the increase in the flash point of a commercial oil with a direct increase in both nanoparticle concentration, which is an indicator of the quality of the nano-lubricant, and improves its performance during operation inside the engine. To prevent internal engine parts from being worn during start-up and to avoid the problem of the oil not reaching all engine parts quickly, the lubricant must have a viscosity sufficient to flow easily. Pour point is the lowest temperature at which a liquid, such as an oil or fuel, can still flow by gravity. It indicates a fluid's low-temperature flow characteristics, with a lower pour point meaning the fluid remains liquid at colder temperatures. When a liquid cools below its pour point, wax or other solids can form, causing it to thicken, solidify, and lose its ability to flow.Fig. 17 shows the effect of ZnO and SiO_2 NPs on the pour point behavior of a commercial oil measured using the ASTM-D97 method (Awad et al.,2022; Ali et al.,2016; Ettefaghi et al.,2017). The effect of NPs, specifically ZnO and SiO_2, on the pour point of lubricating oils used at different concentrations was studied to improve their quality, ranging from -36 to -41. The rate of change in the pour point, in this study, ranges between 3 and 6 degrees negative, and this change depends on the type of oil used and the additives added to it (Awad et al.,2022; Ettefaghi et al.,2017). The effect rate of these nanomaterials was good, especially at a concentration of 1.0 % by weight for both materials.And This is to ensure safety inside the engine by preventing oil vapors from burning due to an increase in the flash point and preventing the oil from freezing due to a decrease in the pour point.

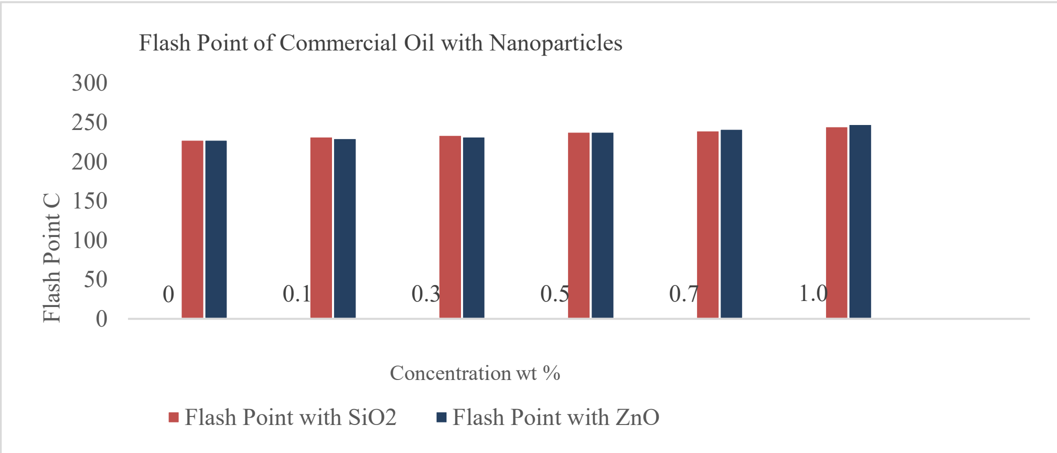

Fig. 16. Effect of adding ZnO/SiO_2 concentration on flash point of commercial oil

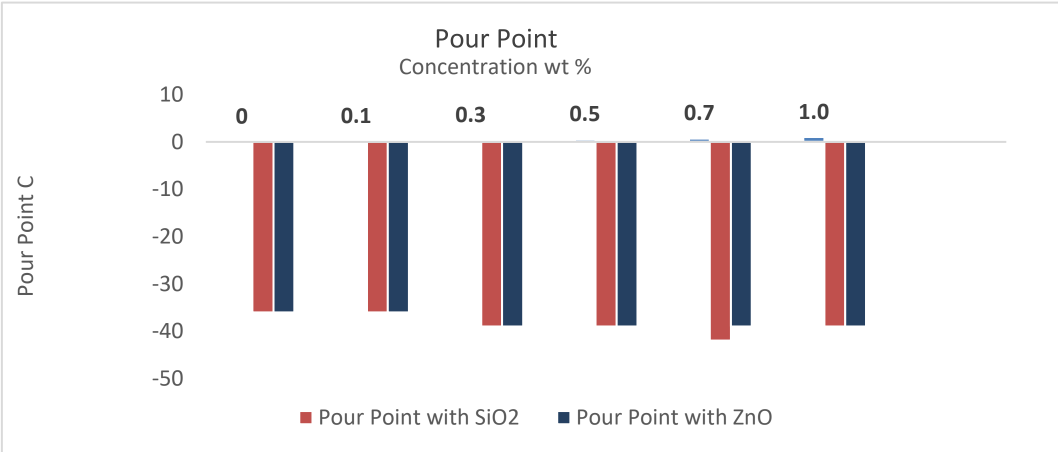

Fig. 17. Effect of adding ZnO/SiO_2 concentration on pour point of commercial oil

4. CONCULUSION

Zinc oxide and silicon dioxide NPs were successfully prepared using the sol-gel method, yielding NPs with specific measured values, properties, and control over purity, shape, diameter, color, and surface area. Adding ZnO and SiO_2 NPs to a commercial oil base resulted in a slight increase in its kinematic viscosity at both 40°C and 100°C.

The viscosity index (VI) of the 5W-20 commercial base oil showed a notable enhancement with

NPs addition. The most significant improvement was achieved by adding ZnO. The flash point of the 5W-20 commercial oil also improved with the inclusion of various concentrations of ZnO and SiO_2 NPs, reaching a maximum value, which is higher than the original oil's flash point. A good enhancement in VI was also achieved when a hybrid type of NPs, ZnO and SiO_2, were blended with the commercial oil, with the best value at the mixing ratio 0.75 wt% ZnO and 0.25 wt% SiO_2.The Novelty of this study is that NPs had been applied to enhance the rheological and tribological properties of commercial lubricating oil not a buse oil as many published research studied. Also, NPs that had been prepared in this work were of high purity surface area , and other properties that enable then to be a solution for low-grade-efficiency lubricating oil . This result obtained for each NPs and for the hybrid of them.

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Not applicable.

Declarations

Competing Interests

None.

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Data Availability Statement

Not applicable.

Author contribution

did conceptualization and reviewing, H. did experiments and writing

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