

The Effect of Nanofluids on the Thermal Properties of Engine Oil (Review)

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Abstract - Due to the increasing expansion in the topic of nanotechnology with an emphasis on different nanoparticles like AlO_3 , CuO , TiO_2 , SiO_2 , and CNTs distributed in base oils, this study offers a thorough literature analysis on the impact of regular and hybrid nanofluid addition on the thermal characteristics and heat transfer performance of engine oils. According to the review, adding nanoparticles to engine lubricants greatly increases their thermal conductivity, specific heat capacity, and overall heat transfer rate; gains can range from 10% to 45%, depending on the kind, size, and volume fraction of the particles. Higher concentrations did, however, also result in a rise in density and viscosity, which could have an impact on flow stability and pumping power. Generally speaking, nanoparticle concentrations less than 1.0% by volume yield the best effect. These findings demonstrate how lubricants based on nanofluids can enhance internal combustion engine cooling and energy efficiency while preserving long-term dispersion stability and stable rheological behavior.

Keywords: Nanofluids, Nanoparticles, Hybrid Nanofluids, Thermal Conductivity, Viscosity Index, Lubricating Oil.

I. Introduction

Technological developments in energy systems, including batteries, electronics, and heat exchangers, are linked to the production of significant heat fluxes that call for proper thermal management. Conventional thermal fluids currently have limited applicability because of their low thermal conductivity. The development of nanofluids as sophisticated thermal fluids is a result of the growing demand for more effective fluids. Many studies have been conducted on the synthesis of nanofluids, which are created by suspending nanosized materials in traditional thermal fluids to enhance their thermal properties. Because it is directly linked to increased thermal efficiency and performance, thermal conductivity is a crucial characteristic for the usage of nanofluids in a variety of applications. The thermal conductivity of nanofluids has been the subject of numerous investigations employing a variety of base fluids and nanoparticles. The size, shape, and type of the nanoparticles,

the type of base fluid and surfactant, temperature, and other variables all affect the TC enhancement values that have been reported [1-8].

The variables influencing nanofluid temperature are shown in Figure (1). Nanoparticles are suspended in a base fluid to create the nanofluid. The concentration of nanoparticles rises in directly proportion with the number of particles suspended in the base fluid. It is anticipated that the addition of nanoparticles will raise the temperature of the prepared nanofluid, with Brownian motion and other mechanisms playing a role [9].

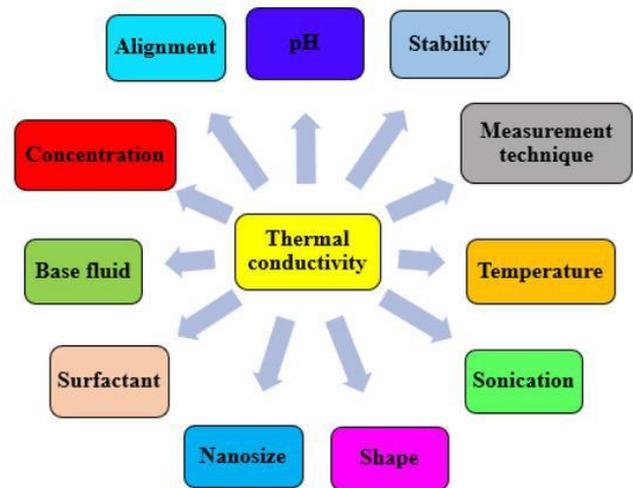


Figure 1: Factors affecting thermal conductivity of nanofluids [9]

For years, a variety of strategies and tactics were used to improve heat transfer efficiency in order to reach the highest possible level. The development of heat transfer improvisation has been the subject of numerous studies and attempts. However, several high-performance thermal systems for heat transfer improvement were developed because of the complexity and wide range of some heat transfer applications. As a result, heat transfer performance increased in stability and growth. Furthermore, the contributions of the working fluid's or material's density, specific heat, viscosity, and thermal conductivity typically determine heat transmission capacities. Heat transfer processes even have a qualitative impact on these thermal characteristics. The dispersion of

nanoparticles in a base fluid, referred to as nanofluids, is one advancement in heat transmission [10–14]. When compared to water, Michael and Inian [15] found that nanofluids greatly enhanced thermal performance. The system's heat transmission is significantly influenced by the thermophysical characteristics of nanofluids, which also show promise for improving thermal performance and efficiency. Furthermore, metals, oxides, and carbon nanotubes (CNTs) make up the majority of nanoparticles. Heat transmission is enhanced when nanoparticles are dispersed throughout the base fluid [16][17]. The primary thermal characteristic that draws attention to the enhancement of thermal performance is the thermal conductivity of nanofluids. Al_2O_3 nanoparticles in water with a 4.3% volume fraction resulted in a 32.4% improvement in thermal performance [18].

New research on the production of nanofluids, known as hybrid nanofluid, has emerged in recent years. Two distinct nanoparticles were used exclusively to create this hybrid nanofluid, which was subsequently dissolved in a base fluid. When compared to a single nanoparticle, the thermophysical characteristics of hybrid nanofluids created a strong tendency towards an improved heat rate, which demonstrated a promising reaction in the heat transfer system. Numerous research are still being conducted to examine the stability and adverse impacts of using hybrid nanofluids in a heat transfer system, since they demonstrated a promising influence. Furthermore, hybrid nanofluids demonstrated a strong reflection of pressure drop and reactivity properties. Hybrid nanofluids were evaluated by researchers, who discovered that they were rare because of their pressure drop condition and sedimentation in a base fluid.

Therefore, the production of a stable and reactive hybrid nanofluid depends critically on the size of the hybrid nanoparticles, surface adsorption, volume fraction, and concentration. Several elements can be taken into consideration in order to assess the stability and consistency of a hybrid nanofluid. These include the hybrid nanofluid's thermophysical characteristics, the researchers' empirical correlation, and the technique used for its synthesis and concentration. When using nanoparticles to increase the thermal conductivity of traditional heat transfer fluids, the preparation of the nanofluid is crucial. For instance, it was discovered that metallic nanoparticle-containing nanofluids had a better thermal conductivity than non-metallic (oxide) nanoparticle-containing nanofluids. The greater the heat conductivity of nanofluids, the smaller the particle size [10,13,19-21].

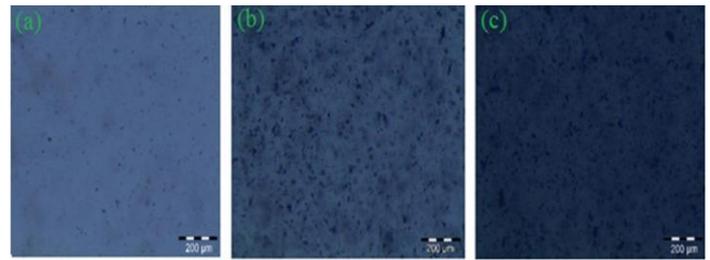


Figure 2: Optical images of ACG/EG hybrid nanofluids at different concentration (a) 0.02%, (b) 0.04% and (c) 0.06% [22]

II. Improving Performance and Efficiency with Nanofluids

In this study, several research groups discussed various aspects of improving the performance and efficiency of motor oils using nanofluids consisting of a single type of nanoparticles or hybrids of two or more types of nanoparticles. Various methods and materials have been used for this purpose, the most common of which are listed below.

Conventional engine oils' subpar thermal and physical characteristics restrict the longevity and performance of vehicles. The purpose of this study is to examine how 10W30 Mobil engine oil is affected by nanoparticles such as reduced graphene oxide (rGO), iron oxide (Fe_2O_3), titanium dioxide (TiO_2), and fullerene C60. Within the temperature range of 30 to 120 °C, the impact of nanoparticle concentrations at various mass fractions (0.01, 0.05, and 0.1) was investigated in this work. A LAMBDA thermal conductivity meter, which employs the transient hot wire method in accordance with ISO standards, was used to measure the thermal characteristics of the nanofluids after they had been created using a two-step direct mixing process. The stability of the nanofluids was visually observed over a four-week period, and surfactants were not necessary because of the low concentrations of the nanofluids. As a result, the base oil's thermal conductivity increased the most with $\text{TiO}_2/10\text{W}30$ at a mass fraction of 0.1 wt.% at 80 °C, and its specific heat capacity increased with the addition of $\text{Fe}_2\text{O}_3/10\text{W}30$ at a mass fraction of 0.1 at 70 °C; these improvements were 5.8% and 14.4%, respectively. The inclusion of the nanoparticles had little influence on thermal diffusivity, while fullerene C60 had no discernible impact on any thermal characteristic. It was determined that the addition of nanoparticles at various weight fractions and temperatures significantly improved the engine oil's thermal characteristics [23].

In order to improve SAE 10W-40 engine oil's thermophysical properties and performance, this study investigates the creation and optimization of a novel nano lubricant by adding graphene-cellulose nanoparticles. Different concentrations of the nano lubricants (0.01%, 0.03%, and 0.05% by volume) were created, and their tribological characteristics, dynamic viscosity, and thermal conductivity

were all thoroughly assessed under operating conditions. The addition of graphene-cellulose nanoparticles enhanced heat transfer capacities, especially at higher concentrations, while preserving stability over a broad temperature range (30°C–90°C), according to the thermal conductivity analysis. Dynamic viscosity studies showed that graphene and cellulose worked in concert to improve lubrication and dispersion stability; the best results were obtained at a concentration of 0.03%. Tribological testing verified a notable decrease in the coefficient of friction, reaching a value as low as 0.0406 and indicating enhanced resistance to wear. The input parameters were optimized using Response Surface Methodology, which shed light on the relationships between temperature, speed, load, and concentration. The results demonstrate the potential of graphene-cellulose nanocomposites as high-performance, environmentally friendly additives for vehicle lubricants, opening the door to long-lasting and energy-efficient uses in the industrial and automotive sectors [24].

The effects of graphene oxide (GO) nanosheets as an addition in fully synthetic SAE 10W-40 engine oil are examined in this work. GO was added at quantities of 0.5, 1.0, 1.5, and 2.0 mg/mL. Thermal conductivity rose by 4–15% and the viscosity index (VI) by up to 7%. The best results were obtained by adding 1.5 mg/mL GO nanosheets, which reduced the coefficient of friction (COF) by 17% and the total wear mass loss by 44% on average, according to tribological experiments using a ball-on-disc mechanism. According to dynamometer engine friction studies, GO nanosheets increased mechanical efficiency by up to 2.8% at specific engine speeds and decreased motored torque by up to 6%, which indicates engine frictional losses. Across all engine speeds, there was an average improvement of 2.6% in brake-specific fuel consumption (bsfc) and 2.7% in brake thermal efficiency (bte). According to the results of thorough engine testing, the GO nanosheets additive may improve internal combustion engines' mechanical efficiency, which would save fuel and energy and indirectly lower CO₂ emissions [25].

The viscosity of SAE 5W50 oil enhanced by MWCNT and ZnO nanoparticles with a 1:4 combination ratio is experimentally examined in this work at temperatures ranging from 5 to 55 °C and solid volume fractions of 0.05, 0.1, 0.25, 0.5, 0.75, and 1%. The purpose of the study is to determine whether it is feasible to create a customized nano-engine oil that uses nanoparticles to reduce cold start engine damage. The generated nano oil with concentrations below 0.25% was chosen as modified engine oil based on the results. One of the most intriguing findings of this study was the nearly 9% decrease in viscosity of nano-oil with a solid volume fraction of 0.05% in comparison to regular engine oil at 5°C and a shear rate of 666.5 (1/sec). This makes pumping easier and allows the oil to enter the lubrication cycle more quickly,

reducing cold start damage. Additionally, the presence of nanoparticles enhances engine part heat transfer. The outcome shown that our suggested nano-oil is more suitable for high temperature use as well, with solid volume fractions below 0.25% and a temperature range of 35 to 55 °C. This is because its viscosity is less dependent on temperature than that of pure 5W50 engine oil [26].

The thermal conductivity of micro- and nanofluids was measured in the current investigation using the hot wire method. Additionally, the heat conductivity and viscosity were estimated using the Einstein and Hamilton-Crosser correlations, respectively. The discrepancies between calculated and experimental results were discovered through comparison. Additionally, it was discovered that engine oil's thermal conductivity rose by 57% and 23%, respectively, when 3 weight percent of TiO₂ nanoparticles or microparticles were added. For the same quantity of TiO₂ nano- and microparticles, the corresponding increases in viscosity were 8% and 7%, respectively [27].

The MWCNT-CuO (20%–80%)/SAE50 nanofluid (NF) is investigated in this work by taking into account the solid volume fraction (SVF), shear rate (SR), and temperature variations. SVFs of 0.0625, 0.125, 0.25, 0.5, 0.75, and 1% are examined, and the temperature range is 30 to 50 °C. A Brookfield CAP 2000+ viscometer is used to measure viscosity. The findings demonstrate that the power-law index values are changeable and that the NF exhibits non-Newtonian behavior. Because the intermolecular distance and intermolecular forces both increase when the NF's temperature rises, the viscosity falls. Viscosity is increased by increasing the SVF in all SVFs except SVF = 0.0625 and 0.125%; for this reason, SVF = 0.0625 and 0.125% are particularly significant. With the response surface technique (RSM), the viscosity of NF may be accurately modeled, resulting in R² and R²-adj values of 0.9993 and 0.9992, respectively. In higher SVFs, adding 10% of the SVF increases the sensitivity of NFs [28].

The special qualities of nano-lubricants have drawn the attention of numerous academics. The rheological behavior of a new generation of lubricants has been examined in this study. MWCNTs with an external diameter of 5–15 nm and an internal diameter of 3–5 nm, coupled with SiO₂ nanoparticles with an average diameter of 20–30 nm, have been mixed with 10W40 engine oil as a base lubricant, resulting in the creation of a hybrid nano-lubricant that contains 20%–80% SiO₂. Below 55°C, the behavior of the nano-lubricant is of the Bingham pseudo-plastic type and is consistent with the Herschel-Bulkley model. Additionally, the behavior of the nano-lubricant has altered to that of a Bingham dilatant at 55°C. The suggested nano-lubricant has a 32% higher

viscosity than the base lubricant (Dynamics Viscosity Enhancement) [29].

The tribological behavior of titanium oxide nanoparticles added to mineral-based multigrade motor oil was investigated in this work. Every test was conducted with varying loads and lubricating oil nanoparticle concentrations. Pin-on-disc tribotester was used for the wear and friction tests. It has been shown that using nanoparticles as lubricant additives can significantly enhance the lubricating qualities. This occurred because, when lubricant flowed through the nanoparticles, the friction coefficient decreased, causing the sliding friction to convert to rolling friction [30].

The thermal and rheological characteristics of Behran oil-based nanofluids made with three readily manufactured and reasonably priced nitride nanoparticles—boron nitride (BN), carbon nitride (CN), and boron carbon nitride (BCN)—are systematically evaluated experimentally in this work. To increase dispersion stability, each nanoparticle was surface-functionalized and distributed at 0.1–0.5 weight percent concentrations. At 25 °C, 35 °C, and 50 °C, measurements were made of thermal conductivity, viscosity, specific heat capacity, and convective heat transfer coefficient. FTIR, XRD, SEM, TEM, and DLS studies were used to validate the nanostructures' structural and morphological properties. While CN produced the largest increase in specific heat capacity (414% at 25 °C), the nanofluid containing BN had the highest thermal conductivity enhancement (14.92% at 0.3 weight percent and 50 °C). In both characteristics, BCN showed modest improvements. At 50 °C, all nanofluids showed negligible viscosity increases (<1%), indicating that they would be suitable for high-performance thermal systems. These findings demonstrate the possibility of functionalized nitride nanostructures as useful additives to enhance industrial lubricants' capacity for heat transmission [31].

Engine lubricants that possess both thermal and tribological qualities are necessary for engines to run efficiently. The main goal of this work is to investigate how different properties of paraffinic base oil (PBO) are affected by a nanocomposite made of graphene oxide (GO) and Cu-TiO₂ nanoparticles. These characteristics include viscosity, flash point, specific heat capacity (Cp), viscosity index (VI), thermal conductivity (k), and tribological elements such as coefficient of friction (COF) and wear rate. This study represents the first time the Cu-TiO₂-GO nanocomposite has been used in paraffinic base lubricants. A pin-on-disc tribometer and KD2 PRO system are used to assess the tribological characteristics and thermal features of lubricants. The study's main achievements include a decrease in the average COF of 9.9%, 29.11%, 19.31%, and 29.8% when employing sample A under the corresponding conditions of 50

N-100 rpm, 50 N-180 rpm, 100 N-100 rpm, and 100 N-180 rpm. The presence of the nanocomposite in the tribofilm was verified by the X-ray photoelectron spectroscopy spectra for Cu 2p, Ti 2p, O 1s, and C 1s. Improvements in k are noted for the sample C nanofluid at 25°C, 45°C, and 65°C levels. In particular, as compared to the base oil, the k rises by approximately 13.46%, 24.65%, and 34.69%, respectively [32].

The application of nanoparticles improves the cooling, lubricating, antifriction, and thermal conductivity of different oils. Likewise, the oil's wettability is greatly enhanced by the nanosuspension. The ethylene glycol-based nanofluids' thermal conductivity increased by 11.85%, while the water-based nanofluids' improved by 19.14%. Likewise, the viscosity of the nanofluids based on ethylene glycol and water rose by 1.42 and 1.70 times, respectively [33].

Engine moving parts such as cams, followers, crank shafts, connecting rods, and other rotating parts greatly benefit from lubricant oils. As lubricant oil additives, nano oxide particles are crucial for their ability to reduce wear and friction during mechanical operation. This study examined the tribological behavior of two lubricating oil types that were dispersed by varying concentrations of titanium oxide (TiO₂) and silicon oxide (SiO₂) nanoparticles. The tribometer test-rig was used to conduct the experiments under normal load at 40°C, 80°C, and 100°C. The nano oxide additions utilized have weight percentages of 0.5% and 1.0%. When 1.0% weight of (TiO₂) was added to mineral and semi-synthetic lubricating oils at 80°C and 100°C, respectively, the lowest values of the friction coefficient and wear rate were obtained. On the other hand, adding (SiO₂) to engine oils does not significantly lower the friction coefficient [34].

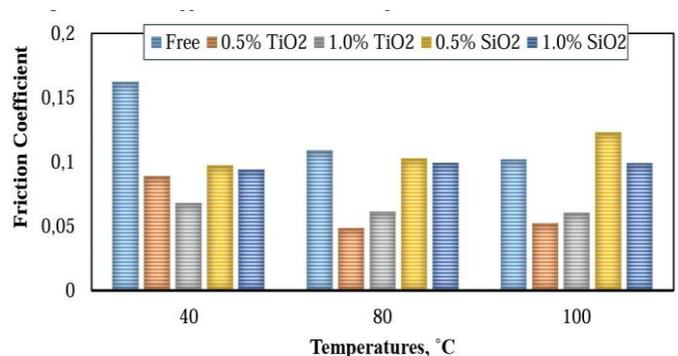


Figure 3: Comparison between different Additives on friction coefficient

An efficient method for enhancing engine performance and emissions is the use of nanoparticle additions in engine oil. To measure the effects of microscopic characteristics of the interfacial layer between the carbon-carbon, carbon-hydrogen, carbon-oxygen, and hydrogen-oxygen molecules under fixed shear rate 600 s⁻¹, graphene, graphene-MWCNT,

and graphene-SiO₂ hybrid nanoparticles were dispersed in engine oil (n-decane) in this study. Nanoindentation operation is used to illustrate the boundary lubrication conditions. Atomic contact produces molecular forces during indentation and scratching operation, which enable the nucleation and spread of dislocation in the planes. The outcome demonstrates that plastic deformation takes place in the lubricating substrate around the indenter during the initial stages of nanoindentation. Additionally, compared to the forces generated in the x- and y-directions, the forces generated in the z-direction have a larger impact. According to the results of nanoindentation, graphene-MWCNT/engine oil (n-decane) nanoparticles performed better than any other nanolubricant at a volume fraction of 1.8%. At a 0.3% volume fraction, 2.5% graphene nanolubricant, 4% graphene-MWCNT nanolubricant, and 8% graphene-SiO₂ nanolubricant enhanced the adhesion between the solid and liquid interface. At 1.8% volume fraction, graphene-MWCNT nanolubricant increased by 240%, graphene-SiO₂ nanolubricant increased by 72%, and graphene-SiO₂ nanolubricant increased by 20%. This pattern suggests that while graphene nanolubricants and graphene-MWCNT nanolubricants perform better at high volume fractions, graphene SiO₂ nanolubricants function better at low volume fractions. Additionally, we saw how the indenter scratched the nanolubricants [35].

One of the newest cutting-edge innovations in lubrication research is nanolubrication. In order to study the tribological properties of these lubricants on a specific tribopair under various operating settings, several types of nanoparticles are dispersed in varying concentrations in the conventional lubricant. It is possible to think about nanoparticles as possible lubricant additives. Compared to the organic molecules currently utilized as lubricant additives, they provide a number of significant advantages, one of which is their nanometer size, which makes it easy for them to access the contact region. When nanoparticles are trapped between the mating surfaces, the actual contact area is reduced. At room temperature, they are frequently effective. Therefore, to acquire intriguing tribological features, no induction period is required [36].

An automobile engine's overall performance, longevity, and efficiency are determined by a number of important aspects. Engine oil is used in internal combustion engines for cooling and lubrication, and its qualities and characteristics are very important. This study compared the effects of Fe₂O₃, TiO₂, and fullerene-C60 (99.5%) nanoparticles on the thermal characteristics of C.A.L.T.E.X. red engine oil in grades 10W30, 20W40, and 20W50. The effects of a 0.01 weight percent nanoparticle concentration in various engine oil classes at temperatures ranging from 30 to 120 °C were the main focus of this investigation. Using an ultrasonicator and a

magnetic stirrer, the two-step direct mixing approach was used to create the nanofluids, guaranteeing that the nanoparticles were evenly distributed throughout the base fluids. The FLUCON LAMBDA thermal conductivity meter was used to measure the base fluids' and nanofluids' volumetric heat capacity, thermal conductivity, and thermal diffusivity. The flash point tester was also used to measure flash points. The thermal characteristics of TiO₂ and Fe₂O₃ were found to be significantly enhanced, but fullerene only displayed a flash point of 212 °C [37].

This experimental investigation was conducted to improve engine oil's effectiveness using a nanotechnology method. Graphene oxide (GO) nanoparticles' atomic and surface structures were examined using X-ray diffraction and a field emission scanning electron microscope. A two-step process was used to create the nano lubricant. Dynamic light scattering was used to analyze the stability of the nano lubricant. Numerous characteristics, including dynamic viscosity, flash point, cloud point, freezing point, and thermal conductivity, were examined, and the outcomes were contrasted with the foundation oil (Oil-SAE-50). The findings demonstrate that, in comparison to the base fluid, the nano lubricant's thermal conductivity was enhanced. As the temperature increased, so did this increase. Variations in the volume fraction raised the dynamic viscosity, which peaked at 36% in comparison to the basic oil. When compared to the base oil, the effectiveness of the nano lubricant was increased by 13.3% and 12.9%, respectively, as the cloud point and freezing point are crucial parameters for lubricants, particularly during cold seasons. The oil's usability was significantly improved by the 8% increase in flash point. This nano lubricant is ultimately thought to be used as an effective substitute in industrial systems [38].

Almost every engineering field has been impacted by nanotechnology, and tribology is one important field of study where it is particularly important. In this work, several weight percentages (0.2 wt%, 0.5 wt%, and 1 wt%) of CuO and ZnO nanoparticles were added to SAE20W40 engine oil in order to examine its tribological characteristics. X-ray powder diffraction (XRD) and scanning electron microscopy (SEM) were used to examine the nanoparticles' structural properties and surface morphology, respectively. A Cannon Fenske viscometer was used to measure the samples' viscosity, and an Abel Pensky flash apparatus was used to measure the created nanolubricants' flash and fire points. Using a four-ball tester, the tribological and anti-wear qualities were investigated. The findings showed that, in comparison to the other formulations examined in this study, the nanolubricant made by adding 0.5 weight percent ZnO nanoparticles demonstrated higher tribological performance [39].

Improved tribological qualities are provided by nano-lubricants in a variety of applications, including engines and machinery. The lubricating oils wear, friction, thermal, chemical, and physical characteristics are all impacted by the presence of nanoparticles. A possible lubricant addition for increased engine efficiency is titanium dioxide (TiO_2). The impact of 10 W-30 pure base engine oil contained TiO_2 nanoparticles is discussed in this article. The investigation uses four distinct volume concentrations of TiO_2 nanoparticles in the base lubricating oil (0.01%, 0.025%, 0.050%, and 0.075%). Using a four-ball tribometer, the tribological experiments were conducted at room temperature and at 75 °C. The worn surface was examined using an Alicona Inginité Focus G5 microscope and a scanning electron microscope (SEM). The findings demonstrate that the surface-modified TiO_2 nanoparticles can significantly increase the additive oil's load-carrying capacity, friction reduction, and anti-wear properties. The tribological characteristics of the nano-lubricant made at various volume concentrations (VC) are the wear trace's diameter and the coefficient of friction. It was discovered that as the VC of TiO_2 nanoparticles in the lubricating fluid increases, so do the wear scar's diameter and coefficient of friction [40].

High temperature-induced thermal deterioration that reduces the lubricating oil's capacity between friction pairs is one of the main reasons why lubricating oil fails in car engines. The purpose of this study is to thoroughly examine how ionic liquid (IL) and h-BN/ MoS_2 hybrid nanoparticles affect engine oil's thermal performance (5 W-40). According to the rheological results, NL behaves as a non-Newtonian fluid, while IL increased the lubricant's viscosity value by extending the alkyl chains. Thermogravimetric (TGA/DTG/DSC) examination of lube oil's thermal peculiarities was used to investigate the thermal stability of h-BN/ MoS_2 hybrid nano-lubricants modified by IL and to further demonstrate how IL enhanced the thermal properties. The findings clearly demonstrated that the IL and h-BN/ MoS_2 hybrid nanoparticles work in concert to create a complex interaction at high temperatures that can postpone the erosion of the nanoparticles' surface due to high temperatures. In the end, this study found that using hybrid nano-lube oils over a broad temperature range delayed the burnout temperature in thermal degradation by around 8.1% [41].

There are many opportunities for the use of efficient and effective lubricants in the manufacturing sectors. For process cooling and lubrication, minimum quantity lubrication (MQL) machining with low nanolubricant flow rates is being studied. Examines the characterization of wasted lubricants for MQL machining that are a hybrid nanomixture of graphene and aluminum oxide ($\text{G-Al}_2\text{O}_3$). By employing nanolubricants of $\text{G-Al}_2\text{O}_3$ nanoparticles in various volume composition ratios at

a constant 1.0% volume concentration in a base liquid mixture of 40% spent lubricants, this method's primary benefit is the reduction of disposal lubricants to create high-performance cooling lubrication. Prior to performing the dynamic viscosity and thermal conductivity studies, the nanolubricants were stable and homogenous. A four-ball wear tribotester machine was used to assess each ratio's tribological performance. The $\text{G-Al}_2\text{O}_3$ hybrid nanolubricant produced the largest enhancement, up to 29% greater than the base liquid solution, and the thermal conductivity peak value. For every ratio, the dynamic viscosity fluctuation was less than the 40:60 ratio. Particularly for ratios of 60:40 and 20:80, the properties enhancement ratio indicates that $\text{G-Al}_2\text{O}_3$ hybrid nanolubricants with a 1.0% volume concentration facilitate heat transfer. With a 45% improvement over the base liquid solution, the lowest coefficient of friction (COF) for a 60:40 ratio was found to be 0.064. Finally, it was found that the ideal ratios for $\text{G-Al}_2\text{O}_3$ hybrid nanolubricants were 20:80 and 60:40. The combination of improved tribological and thermophysical properties offered greater benefits for cooling lubrication applications in terms of the property's improvement ratio [42].

The thermal conductivity (k_{nf}) of WO_3 -MWCNTs/Engine Oil hybrid nanofluids was measured experimentally in this study, and a novel significance was discovered. WO_3 nanoparticles and MWCNTs were suspended in engine oil using ultrasonic waves to create a nanofluid utilizing a two-step process. The diameter of the MWCNTs is between 20 and 30 nm, while the diameter of the WO_3 nanoparticles is between 23 and 65 nm. The findings show that when the temperature and the volume fraction of nanoparticles (ϕ) increase, the k_{nf} increases as well. Naturally, the ϕ has a greater impact on the k_{nf} than temperature does. Additionally, at $T = 60$ °C and $\phi = 0.6\%$, the hybrid nanofluid's maximum k_{nf} rose by 19.85% in comparison to the basic fluid [43].

This study presents an experimental analysis of how temperature and nanoparticle concentration affect the viscosity of a ZnO-MWCNTs/engine oil (SAE 10W40) hybrid nanolubricant. The tests were conducted again with temperature ranges of 5–55 °C, shear rates ranging from 666.5 to 13,330 s^{-1} , and volume fractions of 0.05%, 0.1%, 0.2%, 0.4%, 0.6%, and 0.8%. The Brookfield digital viscometer (CAP2000) was used to measure the viscosity of the hybrid nanolubricant. At every temperature and volume percent, we discovered that the nanofluid behaves Newtonianly. Additionally, the viscosity of the nanofluid is raised by raising the volume fraction of nanoparticles and nanotubes at a steady temperature. At a constant volume fraction, the viscosity of the nanofluid falls as the temperature rises [44].

An improved microwave platform was used in this study to produce MoS₂-hBN hybrid nanoparticles for novel nanolubricant formulations. Field-emission scanning electron microscopy, energy-dispersive X-ray spectroscopy, X-ray diffraction, and Raman spectroscopy were used to characterize the produced nanoparticles. To create a nanolubricant, the hybrid nanoparticles were subsequently added to 20W40 diesel-based motor oil. The viscosity index, stability, volatility, tribological characteristics, oxidation characteristics, and thermal conductivity of the nanolubricant were among the physical and chemical attributes that were examined. According to the findings, adding 0.05 weight percent MoS₂-hBN hybrid nanoparticles to the oil considerably decreased the wear scar diameter and coefficient of friction by 35.54% and 68.48%, respectively. Furthermore, at 100 °C, it demonstrated a significant improvement in thermal conductivity of 28.30% and oxidation of 38.76%, respectively. These results show that MoS₂-hBN hybrid nanoparticles have the potential to be a useful additive that greatly improves the characteristics of nanolubricant [45].

In several industrial systems, oils are utilized as lubricants and coolants to lessen abrasion and friction between components. Investigating the impact of adding an Al₂O₃-Fe₂O₃ nanopowder hybrid on the thermal characteristics of 10w40 engine oil was the aim of this investigation. The impact of nanoparticle concentration at various mass fractions (0, 0.25, 0.5, 1, 2, and 4) was investigated in this work. The temperature range in which the experiments were carried out was 25–65 °C. The two-stage process was used to prepare the nano-lubricant. To evenly disperse the nanoparticles in the base fluid, an ultrasonic probe was employed for forty-five minutes. Using the KD2-Pro thermal analyzer, the hybrid nanofluid's thermal conductivity coefficient was determined. The findings showed that even the smallest mass concentration enhanced the nano-lubricant's thermal characteristics. Consequently, at a mass fraction of 4%, or 33% of the base oil, the most improvement was observed [46].

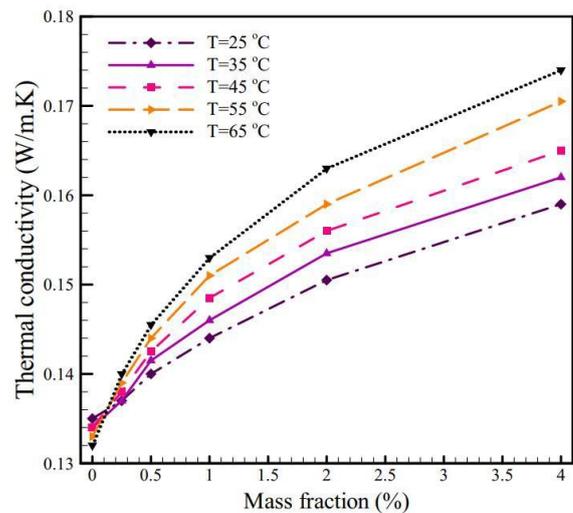
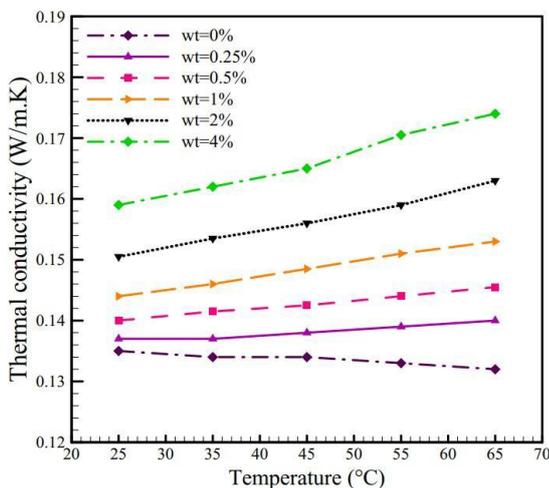


Figure 4: Effect of Temperature and mass fraction on thermal conductivity of 10w40/Al₂O₃-Fe₂O₄ nanolubricant

The contribution of Al₂O₃/TiO₂ hybrid nanoparticles as nanolubricants to increase fuel economy and gasoline engine efficiency is the subject of this study. An AVL dynamometer was used to experimentally assess the performance characteristics of gasoline engines under various operating situations, such as the New European Driving Cycle (NEDC). The engine was also evaluated during the warm-up phase, which is a vital operational condition. The findings demonstrated that, in comparison to engine oil without nanoparticles, the use of Al₂O₃/TiO₂ nanolubricants increased brake power, torque, and mechanical efficiency while lowering brake specific fuel consumption (BSFC) due to the engine's improved mechanical efficiency by 1.7–2.5%. Therefore, during NEDC, vehicle fuel consumption in urban areas could be reduced by up to 4 L per 100 km. Additionally, in order to connect laboratory tribological testing with real engine performance, FESEM, EDS line scanning, XPS, and Raman spectroscopy were used to comprehend the primary tribological causes for enhancing engine performance. In the end, the findings imply that nanolubricants offer cost-effective engines with high efficiency, which may be a suitable course of action for automakers and consumers to reduce engine fuel costs while maintaining engine durability under various operating circumstances [47].



The impact of AlO₃-MWCNT on the engine oil (10W40) base fluid's thermal conductivity was examined in this study. Because thermal conductivity depends on temperature and the quantity of nanoparticles, the experimental tests were carried out at 25–65 °C with volume fractions of 0.05, 0.1, 0.25, 0.5, and 1 vol%. Additionally, to confirm the long-term stability, two separate zeta potential tests were conducted. According to experiment data, the oil's capacity to transfer heat at 65°C is roughly 4.4% less than that at 25°C while the temperature gradient remains constant. However, adding 1 vol% of AlO₃-

MWCNT nanoparticles to the oil increased the heat transfer potential by 9.62%. It was discovered that the benefits of incorporating MWCNT- AlO_3 nanoparticles into engine oil (10W40) on improving thermal conductivity were enhanced at higher temperatures. The addition of MWCNT- AlO_3 to oil increased thermal conductivity by up to 30.53% [48].

The rheological behavior of engine oil with different concentrations of hybrid nano-additives has been investigated in this article. The trials were conducted at temperatures between 25 and 50 degrees Celsius and in the solid volume fraction range of 0 to 1.0%. Viscosity experiments at the 1333–13,333 s^{-1} shear rate range demonstrated that the Al_2O_3 -MWCNTs/SAE40 hybrid nanofluid behaved Newtonianly at all temperatures and solid volume fractions taken into account. Additionally, experimental results showed that when the concentration of nano-additives grew and the temperature decreased, the hybrid nanofluid's viscosity increased. The hybrid nanofluid's relative viscosity results indicated that the viscosity might be increased by up to 46%. According to the results of a sensitivity analysis, viscosity is more sensitive to changes in the solid volume fraction than it is to temperature changes [49].

In this analysis, we examine the energy transference via Prandtl-Eyring nanofluid flow over a heated stretching surface based on motor oil. Copper (Cu) and titanium dioxide (TiO_2) nanoparticles (NPs) are added to engine oil, the base fluid, to create the nanofluid. Exposure of the nanofluid flow via the heated slippery surface allows for the observation of the flow mechanism and thermal transmission. This study additionally elaborates on the effects of radiative flux, heat absorption/generation, and permeable surface. A system of PDEs has been used to design the flow of nanofluids, and similarity modification is used to convert the PDEs into a collection of ODEs. The acquired nonlinear collection of non-dimensional ODEs is solved numerically using the "shooting method." Tables and charts provide a tangible example of the results. It has been found that the buildup of nanomaterials in engine oil speeds up the rate of energy transfer while lowering skin friction. The porosity factor and volume fraction of NPs stimulate a large deceleration of the velocity field. However, when the porosity factor and volume fraction of NPs are encouraged, the temperature profile dramatically increases [50].

III. Conclusions

It is evident from the combined findings that ordinary and hybrid nanofluids significantly affect the thermal and physical properties of engine oils. By adding metal and oxide nanoparticles, thermal conductivity and heat dissipation capacity are continuously increased, which helps engine

components regulate their temperature more effectively. By carefully choosing the type and quantity of nanoparticles, these effects can be mitigated, even though modest increases in viscosity and pressure drop may occur. Furthermore, better lubrication, lower friction losses, and longer engine life are all facilitated by nanofluids' superior heat transfer qualities. All things considered, engine oils based on nanofluids are a potential next-generation cooling and lubricating oil technology that, when installed and designed correctly, can improve performance and have positive environmental effects.

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