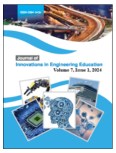

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Augmentation of the lubricant heat transfer performance by exploiting the efficacy of Al_2O_3/ZnO hybrid nanoparticles as additives: An experimental analysis

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Abstract

In the present study, merely emphasis is placed on the effect of Aluminum Oxide/Zinc Oxide hybrid nanoparticle (HNP) blended in the SAE 15W40 engine oil lubricant at two different concentrations of 0.1% and 0.01% by weight in the thermal range of 33 0C to 88 0C, compared and investigated to normal engine oil thermophysical properties while leaving aside tribological characteristics. First, hybrid nanoparticles prepared by the sol-gel technique and then subsequently prepared HNP underwent characterization techniques such as X-ray diffraction (XRD), UV-visible spectroscopy, and Fourier Transform infrared (FTIR) spectroscopy, to ascertain the morphology of the synthesized samples and particle sizes. The prepared HNP has been blended with the lubricant using ultrasonication to yield a hybrid nanofluid (HNF). Moreover, the Zeta Potential Test was conducted to determine the stability of the HNP within the host fluid engine oil. Similarly, FTIR and UV-vis spectroscopy techniques were employed for subsequent characterization techniques of HNF. The present research study explored the increment in heat dissipation rate in engine oil due to the involvement of Aluminum Oxide/Zinc Oxide HNP thereby reducing the cooling load which was calculated by the experimentally measured temperature differences and calculated specific heat capacity. Comparing pure engine oil with the HNP added at two different concentrations 0.1% and 0.01% wt. in the engine oil revealed that the enhancement on the thermophysical properties of lubricants specifically Viscosity, Pour Point by 35.4% and 0.2% and, again engine performance testing between the normal and hybrid nanoparticle-based engine oil separately concluded that the average heat transfer rate on hybrid metal oxide-based nanoparticle is higher than the normal base oil.

1. Introduction

Minimal heat transfer rate through conduction and convection is a main constraint in developing energy-efficient heat transfer fluids required in many industrial and commercial applications. The heat rejection requirements are continually increasing due to trends toward more power output for engines, and higher heat byproducts of the devices during their operation. Conventional techniques to increase heat flux rates include extended surfaces such as fins and microchannels and/or rising flow rates by increasing pumping power. However, current design solutions already push the available technology to its limits [1]. Developing new advanced fluids with improved thermal properties is crucial to solving this problem. Enhancing the thermal properties of fluids can be accomplished by including high thermal conductivity nanoparticles or hybrid nanoparticles into the fluid. Maxwell was the first to suggest suspending conductive particles in fluids to increase heat transfer

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[2]. The suspensions of nanometer-sized particles as an innovative idea inside the host fluid has been discovered by Eastman Choi as a breakthrough in defining nanofluids [3].

The reciprocation motion of an internal combustion (IC) engine creates friction, which can generate heat and cause wear on the engine components. The lubrication is necessary to reduce friction and wear for smooth engine running. The cylinder walls are coated with a thin layer of lubricant, typically engine oil. This engine oil absorbs heat and lowers friction by creating a film between the piston and the cylinder walls. An engine would rapidly overheat and seize without oil, causing failure. Lubricants aid in reducing this issue and, when monitored and kept properly, can lengthen engine life. The use of hybrid nanofluids after mono nanofluids has proved to be a reasonable choice for improving the engine cooling rate and easing the complex nature of the thermal management system [4][5].

Before hybrid nanofluid was introduced in 2011, all researchers were focused on discovering better heat transfer fluid (HTF). This novel dispersed single nanoparticles in a base fluid resulting in a mono nanofluid as a promising HTF and studying its enhancement of thermos-physical and tribological properties [6]. The research investigated the rheological behavior of SAE 50 oil at different temperatures adding zinc oxide nanoparticles [7]. Viscosity measurements at various shear rates revealed that all nano-lubricant samples had Newtonian behavior and a new positive correlation as a function of ZnO volume fraction and temperature has been proposed to predict the viscosity of the nano-lubricant. The research showed an increment in thermal conductivity of SAE 50 engine oil up to 8.74 % by adding zinc oxide nanoparticles in direct proportion to the concentration and temperature [8]. Other studies concluded that with the addition of ZnO nanoparticles at various concentrations in the SAE 20W50 engine oil, viscosity increased up to 37%, leading to significant changes in mechanical efficiency [9]. Experimental data established the thermal conductivity ratio of tested nano-lubricant to base oil. More studies investigated the tribological properties of zinc oxide (ZnO), multi-walled carbon nanotube (MWCNTs), and ZnO/MWCNTs hybrids as lubricant additives in commercially available 10W40 engine oil [10]. The tribological results revealed that the ZnO/MWCNTs hybrid nanomaterials in the engine oil exhibited significantly enhanced friction reduction and higher anti-wear capability than that of the pure oil, ZnO, and MWCNTs nanoparticles added oil [11].

Likewise, Al_2O_3 nanoparticles have been added to the host fluid to produce nanofluids. Al_2O_3, has a property of better chemical inertness and stability but has a drawback of low thermal conductivity. Metallic nanoparticles such as copper, silver, and zinc exhibit remarkable thermal conductivity, but they are chemically reactive and unstable. To trade-off between properties, hybrid nanofluids have been introduced to acquire enhanced properties, suitable for applications that involve remarkable thermal, optical, and rheological properties of the working fluid [12].

Besides engine coolant, lubricant mixed with Al_2O_3 maiden research is carried out to determine the nanofluid kinematic viscosity and density measurements of a synthetic polyester-based Al_2O_3 nanoparticle dispersion. The kinematic viscosity was a function of temperature, nanoparticle mass fraction, surfactant mass fraction, and nanoparticle diameter [13]. A linear relationship was established for liquid-specific volume to temperature. In another research viscosity, density, and thermal conductivity measurements of synthetic polyester-based added Al_2O_3 and ZnO nanoparticles separately prepared mono nano lubricant increment with increasing nanoparticle fraction [14]. Again, Kedzierski et al. determined the specific heat of the liquid, which exhibited that the specific heat of the nano lubricant linear positive correlation with temperature, and a linear negative correlation concerning nanoparticle mass fraction [15]. A tribological study of boundary lubrication phenomena of SAE 20W40 dispersed with Al_2O_3 nanoparticles was investigated. It was found that nanoparticles significantly improved the lubrication properties of oil. Moreover, the tribological properties of Al_2O_3 nanoparticles as lubricating oil additives illustrated that the modified Al_2O_3 nanoparticles with a concentration of 0.1% weight effectively enhance the lubricating behaviors compared to the base oil. Rolling friction replaced sliding friction as the wear mechanism, and a self-laminating protective coating formed on the friction surface [16]. The research was conducted for the tribological characteristics of prepared nanofluid with jojoba oil as host fluid, with different concentrations of Al_2O_3 nanoparticles decreased in friction force value up to a certain level [17].

The Al_2O_3/ZnO hybrid nanoparticles exhibit unique physicochemical properties that make them attractive for various applications, including their use as lubricant additives. With an alumina (Al_2O_3) core and ZnO shell, these hybrid nanoparticles have a core-shell structure. The synergistic combination of the properties of the two metal oxides results in enhanced thermal stability, mechanical strength, and tribological performance compared to individual Al_2O_3 or ZnO nanoparticles [18]. The high surface area and surface reactivity of the Al_2O_3/ZnO hybrid nanoparticles allow for efficient dispersion and adsorption on metal surfaces, leading to improved load-bearing capacity and wear resistance in lubricated systems. Additionally, the unique morphology and tunable composition of these hybrid nanoparticles can be tailored to optimize their anti-wear and anti-friction properties for specific lubricating applications.

Hybrid nanofluids are colloidal suspensions that contain hybrid nanoparticles dispersed in a host fluid, such as water, oil, or ethylene glycol. They proved that hybrid nanofluids have enhanced thermal, optical, rheological, and morphological properties compared to conventional nanofluids, which only contain one type of nanoparticle. The creation of hybrid nanofluids is driven by the desire to increase heat transfer characteristics through improved thermo-physical properties and increased thermal conductivity [19]. The review paper also demonstrates that hybrid nanofluids are more effective HTF than mono nanoparticles nanofluids or conventional fluids [20].

However, the more closely associated research utilizing the same hybrid nanoparticles and mono nanoparticles added on different host fluids has been analyzed and concentrated on its tribological properties and limited study on thermophysical properties. In another research, the performance of the lubricating oil using ZnO/ Al_2O_3 composite nanoparticles as additives is better in comparison to utilizing individual pure ZnO and Al_2O_3 nanoparticle additives, which was examined by using the fourball and thrust-ring test [16]. Experimental analysis of the research proved that the lubricant performance increases remarkably with an optimal concentration of nanoparticle additives, which was 0.1 wt% for the tested ZnO/ Al_2O_3 composite nanoparticles. Compared with the pure ZnO and Al_2O_3, the ZnO/ Al_2O_3 composite nanoparticles as lubricant additives exhibit good antifriction and anti-wear. The ZnO/ Al_2O_3 hybrid nanoparticles augment the lubrication properties by altering the sliding friction into rolling friction and forming a formidable Al_2O_3 protective film after transferring to the friction surface. In the research, both the effectiveness of pollution control and the performance of a diesel engine operating without exhaust gas post-treatment equipment were evaluated by adding zinc oxide and aluminum oxide nanoparticles individually to standard Iraqi diesel [21].

Hybrid nanofluid thermophysical properties measurements exhibited that the density, viscosity, and thermal conductivity of the nanofluid increased. Nanoparticle inclusion resulted in increased thermal efficiency and lower specific fuel consumption. This effect is boosted as a function of nanoparticle concentration. The study results summoned up a significant enhancement in engine performance and a clear decrease in most emissions. Experimental research has been performed on the specific heat and viscosity of Al_2O_3/ZnO water hybrid nanofluids at three mixture ratios [22]. Specific heat capacity decreases as viscosity increases in direct proportion to volume concentration. Al_2O_3/ZnO water hybrid nanofluids at a 2:1 mixture ratio have a maximum viscosity increase of 96.37% maximum specific heat decrease of 30.12% at a temperature of 25 °C and volume concentration of 1.67% [23]. Above all, the use of nanoparticles has the added advantage of serving as a lubricant and coolant [24]. Engine oil acts as a medium or bridge for the heat transfer from the piston generated during combustion to the nearby cylinder lining [19].

Adding Al_2O_3/ZnO hybrid nanoparticles into engine oil has demonstrated remarkable improvements in tribological performance. These nanoparticles act as efficient anti-wear and abrasion-reducing additives, improving the lubricating properties of the oil. Their unique composition and structure enable them to form a protective tribofilm on metal surfaces, which reduces direct asperity-to-asperity contact and mitigates wear. Numerous studies have reported significant reductions in both friction coefficient and wear rate when Al_2O_3/ZnO hybrid nanoparticles are added to coolant [12]. The synergistic effects of the two metal oxides contribute to the enhanced load-bearing capacity, superior thermal stability, and improved anti-scuffing abilities of the lubricant [25]. This leads to improved energy efficiency and extended component lifespan in engine systems. The high hardness and load-bearing capacity of Al_2O_3 nanoparticles, combined with the anti-wear and extreme pressure properties of ZnO, create a synergistic effect that enhances the overall tribological performance of the hybrid nanoparticles. This unique combination of properties helps to maintain the engine oil film thickness and prevent direct metal-to-metal contact, effectively reducing friction and wear in the engine system [21][22][26][27]. Mono nanofluids do not retain all favorable properties that are requisite for dynamic applications in our real world. Therefore, to impart dynamic and variable thermo-physical properties in a hybrid nanofluid revolution in the field of nanotechnology.

Applying these research principles, this research exploits the properties of Al_2O_3 and ZnO nanoparticles as the principal constituent of prepared hybrid nanoparticles. These two contrasting metal oxides are considered, as they possess two different characteristics for meeting our criteria for the performance of the engine. Al_2O_3 is low cost and easily accessible in the market, but most importantly hydrophilic surface properties i.e. easily blended into base fluid and chemically inert as well as excellent mechanical strength despite its low thermal conductivity. To compensate Al_2O_3 minimal thermal conductivity, ZnO has been introduced as the main constitute of HNP to enhance thermal and tribological properties.

Most of the commercially available various grades of engine oil are added with additives to increase the performance. Considering this HNP consists of ZnO/Al_2O_3 as additives in nanoparticle form to enhance thermos-physical and tribological properties. The main reason for performing the secondary function of engine oil as host fluid in HNF is to dissipate the heat generated during the engine running as well as to reduce friction between moving piston and static cylinder wall whilst performing its lubrication operation, utilizing HNP inherent tribological characteristics.

From the literature review, till now specific research on ZnO/Al_2O_3 hybrid nanoparticles dispersing in the SAE 15W40 engine oil for studying the thermophysical properties has not been carried out. This study explores the possibility of adding ZnO/Al_2O_3 hybrid nanoparticles to engine oil, reasoning to enhance the thermos-physical characteristics of the standard SAE 15W40 engine oil. Moreover, this research aims to investigate real IC engine operating conditions for heat dissipation by preparing sample engine oil and novel hybrid nanofluid simulating conditions close to reality.

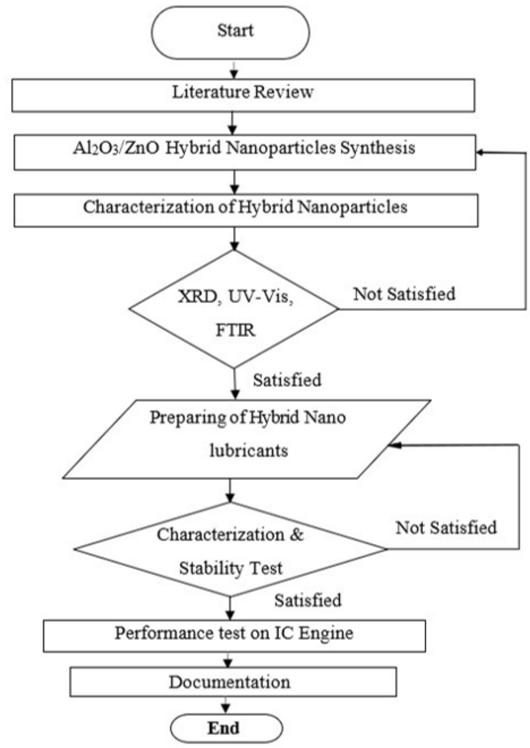

Figure 1: Flow Chart of Hybrid Nanofluid preparation and Testing on IC Engine

2. Materials and Experimental methodology

Experimental investigations were conducted on pure SAE 15W40 Engine Oil as base fluid (lubricant), and Al_2O_3/ZnO hybrid nanoparticles at two different concentrations, 0.1 wt.% and 0.01% by weight blended with the same engine oil as base fluid to prepare Hybrid Nanofluid. All these working fluids have been tested on an ideal engine run as illustrated details in the flow chart Figure 1.

2.1. Experimental procedure

The Al_2O_3/ZnO nanocomposite by Sol-gel pyrolysis method was synthesized at RECAST laboratory at TU, Central Department Balkhu Kathmandu, and NAST. Here, the engine oil is used as the base fluid and the synthesized HNP is the main constituent for the hybrid nanofluid.

The 8 grams of aluminum nitrate and 2 grams of zinc acetate were mixed in a beaker with a solution of ethanol/water (120:80 volume percent). Then 16-grams polyvinyl alcohol (PVA) was added into the obtained nonaqueous (non-hydrolytic) solution, as a solution stabilizer (Sol). PVA exhibits the effect of reducing the particle size of the sample by decreasing the surface tension and improving the dispersion of the reactants during the polymerization reaction. Polyvinyl alcohol (PVA) is a hydrophilic polymer that contributes a hydroxyl group on each of its repeating units, which permits the development of hydrogen bonds with the hydroxyl and carboxyl groups of reactants. The mixture was stirred with the magnetic stir with hot at near about 550 rpm and 50°C, using the control knob of the magnetic stirrer equipment until a transparent and homogeneous solution, which is called sol was obtained. After the sol formation, the mixture was slowly heated to form a homogeneous gel. The formed gel was stirred continuously for one hour at a temperature of 110°C to completely evaporate its solvent and create a dry gel. The same procedure was repeated for the synthesis of HNP.

Then the dried gel was pyrolyzed by PID temperature controller Muffle Furnace for thermal decomposition to obtain calcinated nanocomposite. The dried gel was pyrolyzed at 800°C for 5 h. At this stage, aluminum and zinc salts were decomposed and converted to metal oxides, forming a nanocomposite giving the appearance of white powder. The chemical reaction formula is as follows:

$$\begin{aligned} &2n\,Al(NO_3)_3 + m\,Zn(CH_3COO)_2 \rightarrow \\ &n\,Al_2O_3 \cdot m\,ZnO \quad + 6n\,NO_2 \uparrow \\ &\quad +m\,CO_2 \uparrow \quad +3m\,H_2O \uparrow \\ &\quad\quad + \left(\frac{3}{2}n - m\right) O_2 \uparrow \end{aligned}$$

Where m and n can be varied as the synthesis conditions change.

2.1.1. *Molar calculation:*

The total mass of the reactants used in the chemical reaction are as follows:

$$\text{Mass of Aluminum Nitrate } (Al(NO_3)_3) : 8\,g$$

$$\text{Mass of Zinc Acetate } (Zn(CH_3COO)_2) : 2\,g$$

2.1.2. *Molecular Weight (MW) calculation:*

$$Al(NO_3)_3 = 213.003 \text{ grams/mole}$$

$$Zn(CH_3COO)_2 = 183.424 \text{ grams/mole}$$

2.1.3. *Moles calculation:*

For Aluminum Nitrate $(Al(NO_3)_3)$:

$$\text{Moles} = \frac{\text{Mass}}{\text{Molar Mass}} = \frac{8}{213.003} = 0.03756 \text{ mole}$$

For Zinc Acetate $(Zn(CH_3COO)_2)$:

$$\text{Moles} = \frac{\text{Mass}}{\text{Molar Mass}} = \frac{2}{183.424} = 0.0109 \text{ mole}$$

Considering m and n in the chemical formula is equivalent to unity i.e. 1 and Zinc Acetate is limiting agent in the aboe chemical reaction.

Then
Chemical Reaction formula is reduced into,

$$2Al(NO_3)_3 + Zn(CH_3COO)_2 \rightarrow Al_2O_3 \cdot ZnO + 6NO_2 \uparrow + CO_2 \uparrow + 3H_2O \uparrow + \frac{1}{2}O_2 \uparrow$$

Therefore, Total mass of the hybrid nanoparticles synthesized as

Al_2O_3. ZnO = mole × Molecular Weight = 3.45 gram, in which the composition of nanoparticle ratio of Al_2O_3 to ZnO is 1:2

2.2. Hybrid Nanoparticle synthesis

Al_2O_3/ZnO hybrid nanoparticle was prepared by a wet chemical method utilizing the nonaqueous Sol-gel technique using organic solvent PVA followed by calcination as shown in Figure 2 [28]. The synthesized Al_2O_3/ZnO HNP is known as Ceramic Matrix Nanocomposite (or Hybrid Nanocomposite), which is inorganic and non-carbon NP.

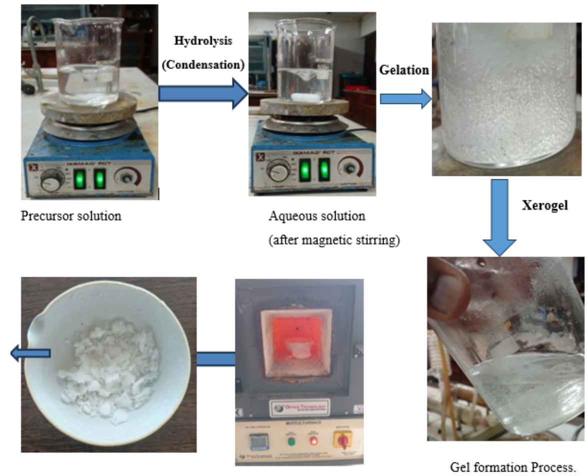

Figure 2: Synthesis of Al_2O_3/ZnO hybrid nanoparticle by Sol-gel process

2.3. Properties of base fluid

TATA Motor Genuine Oil "Diesel Engine Oil CI4 + 15W40" for commercial vehicle SAE grade (multigrade) engine oil produced by TATA Motors Limited is an Indian manufacturer and distributor of TATA genuine parts, automotive oil, additives, and lubricants. The specification of parent oil (base fluid) is specified in Table 1.

Table 1: Typical Physio-Chemical Data: MAK FLEET CI4+ 15W-40

Characteristics	Method	Value
SAE Grade	SAE J300	15W-40
Color	Visual	Brown
Appearance	Visual	Clear
Density at 29.5°C, g/cc	ASTM D1298	0.865
Kinematic Viscosity at 40°C, cSt	ASTM D445	103.5
Kinematic Viscosity at 100°C, cSt	ASTM D445	14.2
Viscosity Index	ASTM D2270	140
Flash Point, °C	ASTM D92	232
Pour Point, °C	ASTM D97	-24

2.4. Preparation of hybrid nanofluid

Hybrid nanofluid was prepared in the laboratory by two-step methods. Monodispersed and hydrophobic aluminum oxide (Al_2O_3) and zinc oxide (ZnO) composite nanoparticles were dispersed 1% weight of concentration in the engine oil as a base fluid without using any surfactant.

After the failure of uniform dispersion of HNP by using both an ultrasonic bath and homogenization utilizing homogenizer equipment, this experiment was shifted toward the ultrasonic probe direct method. This method settled down the undispersed nanoparticles at the bottom of the beaker after performing a sedimentation test of a hybrid nanofluid for three weeks.

Finally, the probe-type ultrasonication process (Model No. Vibra cell 75041) was used to disperse the HNP homogeneously in the base fluid as shown in Figure 3. For this, nanoparticles of about 1000 ppm or 0.1% and 0.01% concentration by weight were mixed into the base lubricant and ultra-sonication was done until the complete dispersion of HNP in the lubricant [29].

Figure 3: Ultra-sonication for preparing hybrid Nanofluid

2.5. Characterization methods of hybrid Nanoparticles & hybrid Nanofluids

FTIR spectroscopy, X-ray diffraction (XRD), and UV-Vis techniques were utilized for the characterization.

Similarly, UV-vis spectroscopy and FTIR tests were conducted for a hybrid nanofluid to determine its metal oxide composite and characteristics. Subsequently, the sedimentation test method (at least one month) of the nanofluid was employed to determine the stability of the dispersed HNP, and Zeta Potential Analysis was performed for the stability test and determined the nanoparticle size in the prepared nano lubricant.

2.6. Thermo- physical properties of hybrid Nanofluid

A hybrid nanofluid was prepared after dispersing the nanoparticles at a concentration of 0.1% by weight or approximately 1000 ppm in the base fluid. The various thermos-physical properties including; density, viscosity, and pour point of the nano lubricants were tested at Nepal Oil Corporation, Sinamangal, Kathmandu.

2.7. Engine Performance Test of the lubricates on an IC Engine

In this study, the engine specification mentioned in Table 2, was operated at 1600 rpm (ideal run condition) with engine load change at steps equivalent to 20% of the total load, shown in Figure 4 [30][31].

The performance testing is carried out in three steps (three days duration) at the Shipradi Company Pvt. Ltd. In the first step, the engine was started at idle conditions and speed using SAE 15W40 TATA CI4 engine oil, and the general vehicle parameters were calculated using the TDS-XENON Yodha/Compact BSIV-EMS BS-4. The measured data is recorded at 5-minute intervals for two hours duration. Similarly, the oil temperature is measured by attaching a temperature sensor to a mobile gauge guide, and the value is read by a smoke meter. The prepared nanofluid lubricant samples with concentrations of 0.01% and 0.1% by weight respectively, were used for further tests. The vehicle parameters are generated using the same diagnostic tool and device and tabulated.

Figure 4: Experimental setup for test IC Engine

3. Results and dicussion

3.1. Characterization of hybrid Nanoparticle

FTIR spectroscopy, XRD, and UV-vis spectroscopy techniques were utilized for the different characterization of HNP including; the morphology of the samples and particle sizes.

3.1.1. UV-visible spectroscopy result

UV-visible spectroscopy was employed to quantify the light extinction, the sum of absorbed and scattered light by an HNP sample. The sample is placed between a light source and a photodetector, and the intensity of a beam of UV-visible light was measured before and after passing through the sample. These measurements were compared at each wavelength to quantify the sample's wavelength-dependent extinction spectrum. The data is typically plotted as extinction as a function of wavelength. Figure 5 illustrated a ZnO nanoparticle peak at 362 nm and corresponding Al_2O_3 at 270 nm whilst comparing the previous research on Al_2O_3/ZnO hybrid nanocomposite structures [32].

Table 2: Specifications of TATA 4SP CR 10 BSIV Engine

Specification	Details
Model	TATA 4SP CR 10 BSIV
Type	Turbo Charged, Inter cooled, direct injection, Common rail diesel engine
No. of Cylinders	4 in-line
Bore / Stroke	97 mm X 100 mm
Capacity	2956 cc
Max. Engine Output	64 KW at 3000 rpm as per MOST / CMVR / TAP-115/116
Max. Torque	250 Nm at 1000-2000 rpm as per MOST / CMVR / TAP-115/116
Compression Ratio	17.5:1
Air Filter	Dry (Paper) Type, Remote mounted
Oil Filter	Spin on type
Fuel Filter	Single Stage fine filtration
Fuel Injection Pump	Common Rail pump
Timing and Governor	EMS ECU Controlled
Capacity of Cooling System	8.5 Liters
Firing Order	1-3-4-2
Engine Oil Capacity	Max. 6.5 liters
Weight of Engine	315 kg (Dry)

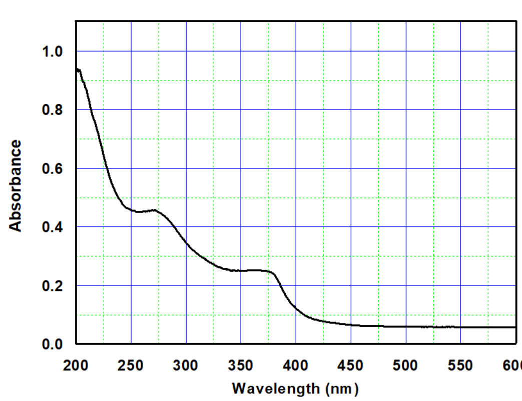

Figure 5: UV- Vis Spectrum of Al_2O_3/ZnO hybrid nanoparticle

3.1.2. *Fourier transform Infrared Spectroscopy result*

FTIR can detect changes in the total composition of molecules by determining changes in functional groups. The vibration and rotation of molecules influenced by infrared radiation at a particular wavelength were measured using FTIR. This method identifies structural differences in molecular binding between entities, which can reveal details about the existence of their interactions.

The Al_2O_3/ZnO nanocomposite characteristic absorption peaks were primarily apparent in the FTIR spectrum, indicating the presence of Al_2O_3 and ZnO bonds. The peak observed in Figure 6 between 3440 to 3800 cm-1 was associated with the OH group derived from Alumina and Zinc Oxide surface.

3.1.3. *X-ray Diffraction result*

XRD provides information regarding the crystalline structure, nature of the phase, lattice parameters, and crystalline grain size. The latter parameter is estimated by using the Scherrer equation using the broadening of the most intense peak of an XRD measurement for a specific sample.

The two sharp consecutive peaks at near about 31 and 36 degrees in Figure 7, vividly show the existence of ZnO nanoparticles and likewise, modest peaks at near about 35.2 and 43.6 degrees show Al_2O_3 [32].

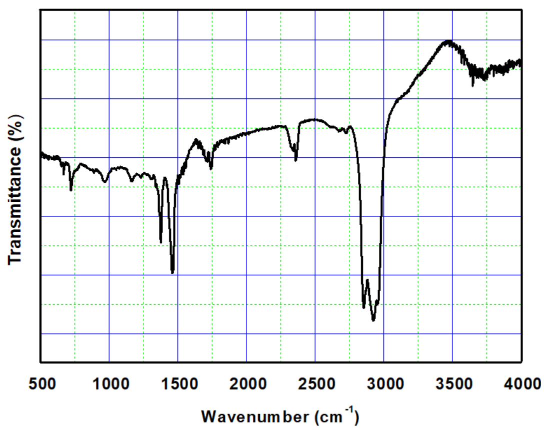

Figure 6: FTIR of Al_2O_3/ZnO HNP

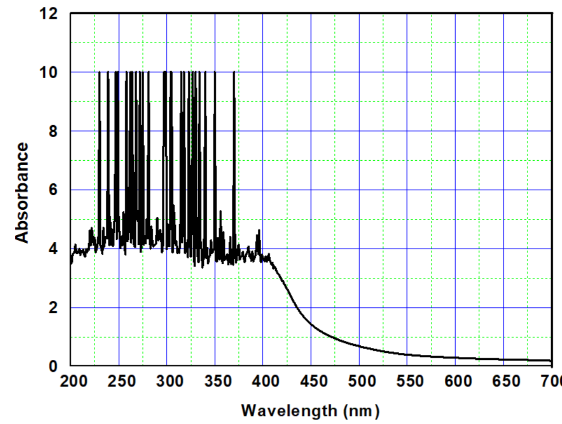

Figure 8: UV-vis graph of HNF

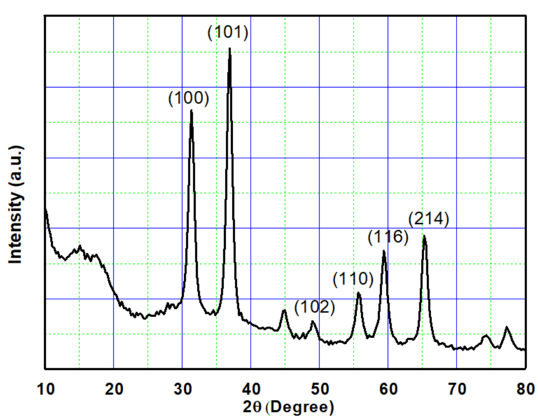

Figure 7: XRD resulting of Al_2O_3/ZnO HNP

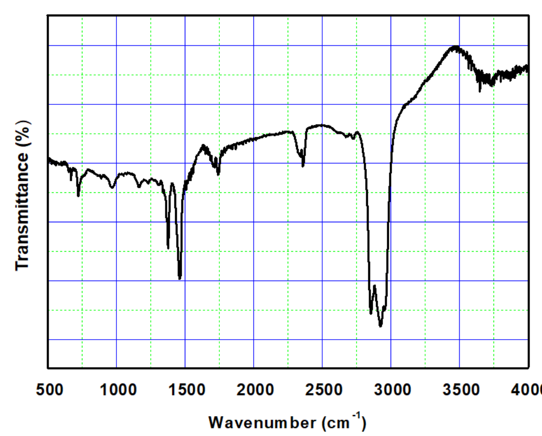

Figure 9: FTIR graph of HNF

3.2. Characterization of hybrid Nanofluid

3.2.1. Physical properties

The density, viscosity, thermal conductivity, flash point, and pour point of the Nano lubricants were determined by corresponding testing. The tests were conducted at Nepal Oil Corporation, and the results are shown in Table 3 below.

3.2.2. UV-visible spectroscopy result

The wavelength between 350 nm to 800 nm as in Figure 8 suggests that base engine oil in the prepared nanofluid whereas all other sharp peaks signify Al_2O_3 and ZnO combination [26].

3.2.3. Fourier Transform Infrared Spectroscopy

The FTIR peak observed between the wavelengths 1650 to 1850 cm-1 of Figure 9 is the peak of pure engine oil [22].

3.2.4. Zeta potential analysis

Zeta Potential is carried out at NAST Laboratory using the specification illustrated in Table 4, finding the particle size and stability of nanoparticles in the base fluid. Figure 10 vivid shows the stability of hybrid nanoparticles in the suspended hybrid nanofluid. Figure 11 depicts that the average diameter of the HNP in the Hybrid Nanofluid from Zeta Potential Analysis is 3.4 nm.

3.3. Engine performance parameter result of the lubricant and hybrid Nano lubricant on an IC Engine

First, the engine performance parameters using base fluid were measured. The measured parameter was compared with the same setup using the Hybrid Nanoparticle as an additive blended in the base lubricant, resulting in improvement on all vehicle parameters like oil temperature and heat dissipation from the engine.

The ambient condition of the test environment is tabu-

Table 3: Comparative Table of thermo-physical properties of base lubricant (SAE 15W40 TATA CI4) vs hybrid nanofluid

Characteristic	Test Method	Normal Oil (15W-40)	Al_2O_3/ZnO HNP Blended Engine Oil
SAE Grade	SAE J300	15W-40	Al_2O_3/ZnO HNP Blended Engine Oil
Color	Visual	Brown	Light grey
Appearance	Visual	Clear	Clear
Density at 29.5°C (g/cc)	ASTM D 1298	0.865	0.8671
Kinematic Viscosity at 40°C (cSt)	ASTM D 445	103.5	158.18
Pour Point (°C)	ASTM D 97	-24	-15

Table 4: Zeta potential test instrument specification

Testing Specification	Value	Unit of Measurement
Temperature of the Holder	24.8	°C
Dispersion Medium Viscosity	0.899	mPa●s
Conductivity	0.183	mS/cm
Electrode Voltage	3.4	V

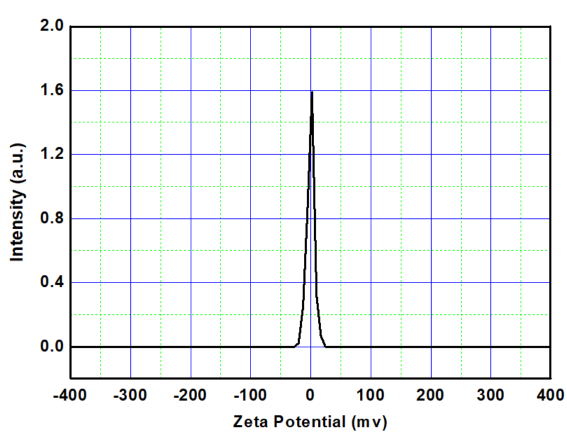

Figure 10: Stability of HNP in the HNF

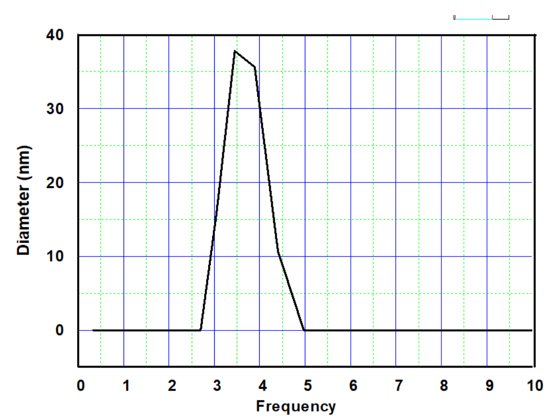

Figure 11: Diameter of HNP solute in HNF

lated in Table 5.

Figure 12 shows that the oil temperature has remarkably increased for a hybrid nanofluid of 0.1% weight of concentration compared to the pure lubricant used in the test engine. Proving the hypothesis of heat dissipation by using engine oil blended with hybrid nanoparticles rather than pure engine oil.

It is noteworthy to mention that the hybrid nanofluid of concentration 0.1% by wt. there is more increment of heat dissipation with an increase in differential temperature in contrast to a concentration of 0.01% by wt. There is a positive exponential correlation between heat dissipation and temperature difference. But in the case for hybrid nanofluid of only 0.01% weight of concentration, even though there seems to slight increment of heat dissipation in comparison to base oil, there exists a constant correlation between heat dissipation and temperature difference. This graphical analysis clears up the negligible effect of 0.01% wt HNP concentration.

Table 5: Ambient Condition Carrying Out Engine Performance Test

Ambient Condition	Value	Unit of Measurement
Ambient Temperature	23	deg C
Ambient Pressure	867	hPa
Wind Gusts	6 (Light Breeze)	km/h
Relative Humidity	38%	-

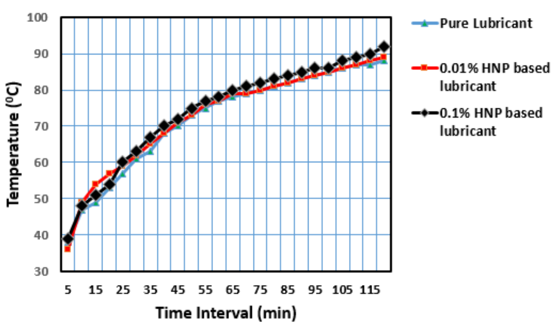

Figure 12: Oil temperature distribution using HNP (0.01% & 0.1%) based Oil and pure Engine Oil

3.4. Analysis of Heat dissipation rate

The heat dissipation pattern of Normal Lubricants and Hybrid Nano lubricants of two different concentrations is depicted on the curve below in Figure 13. This curve clearly shows that there is up to 4.6% increments of heat dissipation while using HNF in comparison with pure engine oil.

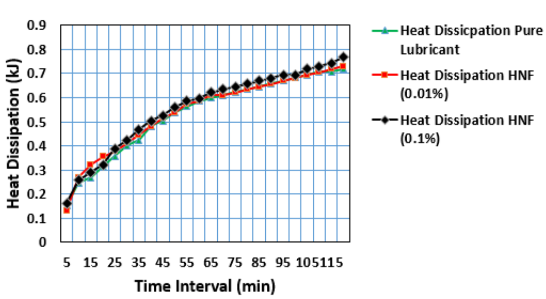

Figure 13: Oil temperature distribution using HNP (0.01% & 0.1%) based oil and pure engine oil

Moreover, previous research papers conducted experimental analysis, calculating the specific heat capacity of engine oil considering constant density with increasing temperature of the engine along the period. This calculated value of SHC by considering the negligible effect of temperature on the oil temperature distribution and SHC, which directly results in the result of calculating Heat Dissipated by the Engine.

This research uses a pragmatic approach, closer to reality, considering the effect of temperature on the density of engine oil. On increasing temperature, there is a corresponding decrement of density. This research has given rising temperature compensation effects on specific heat capacity resulting in changes in heat dissipation. This study bridges the research gap by considering the temperature compensation factor that comes into play of its specific heat capacity.

Similarly, Figure 14, shows the heat dissipation pattern of Normal Lubricants and Hybrid Nano lubricants at two different concentrations taking into account temperature factors. The increment of temperature subsequently decreases density and viscosity resulting in changes in heat dissipation on the below curve. There is also a clear indication of an increment of heat dissipation concerning normal engine oil. An increment of heat dissipation suggests that increase in the cooling effect of the nano lubricant. All these are effects of HNP presence in the base lubricant which enhances thermal conductivity as well as heat transfer characteristics.

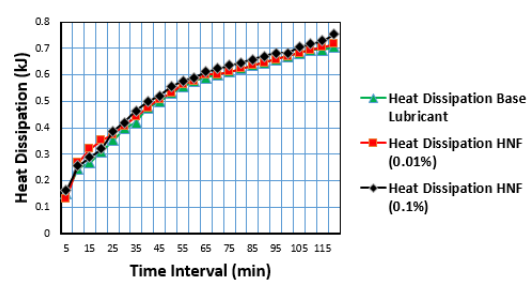

Figure 14: Oil temperature distribution using HNP (0.01% & 0.1%) based oil and pure engine oil considering temperature factor

4. Conclusion

Debunking the Hybrid nanofluid concept, this research concluded that hybrid nanofluids are "composite within composite material" because nanofluid itself is a solid-liquid complex material consisting of solid nanoparticles dispersed in any host liquid. Comparative analysis from the report of NOC, there is an enhancement on the thermophysical properties of lubricants specifically Viscosity, Pour Point by 35.4% and 0.2%.

After the differential temperature analysis and comparing the result of normal lubrication oil (host liquid) and Hybrid Nano lubricants, this research came to the conclusion that adding hybrid nanoparticles to the engine oil increases heat dissipation rate by 4.6%, which allows engine cooling without the addition of external cooling source and removes heat away from moving mechanical components, improves lubrication process as well, which improves the efficiency of the engine and prolongs the life of engine components.

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