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Experimental Investigation in Heat Dissipation Capability of Copper Oxide Nanoparticle Additive Blended Lubricant of Viscosity 15W-40 Operating on A 3.0L Turbocharged Diesel Engine

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Abstract

This study explores the thermal management capabilities of copper oxide nanoparticle additive blended lubricant in internal combustion (IC) engines, focusing on its potential to enhance heat dissipation compared to conventional lubricant. For this, first of all copper oxide nanoparticle was synthesized by using precipitation method and characterized via UV test & XRD test for particle grain size. It was then blended with a conventional lubricant with 0.03% concentration by weight. The nanoparticle blended lubricant was also characterized for thermo-physical properties like density, kinematic viscosity, flash point and pour point. An experimental setup was established, featuring a standard 3.0 L four-stroke turbocharged diesel engine retrofitted with dip probe sensor to measure oil temperature of engine oil sump and a diagnostic software to measure coolant temperature commonly known as engine temperature. Engine tests were conducted under idle running condition for an hour, and the heat transfer rate of both conventional and nanoparticle blended lubricant was determined by analyzing the oil temperature and engine temperature data's. The study observed a 3 °C increase in engine oil temperature from 49 °C with conventional lubricant to 52 °C with CuO-based nano lubricant, indicating enhanced thermal conductivity and improved heat dissipation properties of the nano-lubricant, highlighting the role of nanoparticle additives in reducing engine temperature and potentially enhancing engine life and performance.

Keywords: CuO (Copper Oxide), Heat Transfer Rate, IC (Internal Combustion), Lubricant, Nano-Particle

1. Introduction

Internal Combustion (IC) engines are the powerhouse of the majority of vehicles on the road today and the efficiency of these engines is crucial for performance, fuel economy, and reducing environmental impacts. However, one of the persistent challenges in IC engine operation is managing the heat generated during running of mechanical moving parts, which can significantly affect engine lifespan and its efficiency. Traditionally, lubricants have been used in IC engines primarily to reduce friction between moving parts, subsequently reducing heat and hence lowering wear and tear.[1] However, in minimizing mechanical friction, conventional lubricants have limitations in their ability to dissipate heat generated from the friction between engine's critical components.[2] Recent advancements in nanotechnology have led to the development of nanoparticle-based lubricants, which shows great potential for not only reducing the friction but also significantly enhancing heat dissipation by improving the tribolological characteristics [3]. Conventional lubricants, infused with nanoparticles, can potentially conduct and transfer heat more effectively than the conventional lubricant due to the enhanced thermo-physical properties by nanoparticles [4]. Nanoparticles are very tiny particles usually having a diameter ranging from 1 nm to 100 nm [5]. They have large surface area to volume ratio because as things get smaller, volume decreases more rapidly than their surface area. The exposed surface area is more inevitable than their volume for enhancing the properties of any matter in contact with them [6]. The issue is lack of extensive experimental research on the heat dissipation capabilities of nanoparticle-based lubricants in IC engines, which is hampering knowledge of their potential in enhancing thermal management and overall engine efficiency [7].

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However, experiments in a controlled context are required to test these findings and provide practical insights for application. Improved heat dissipation can lead to decreased energy losses, lower engine operating temperature (coolant temperature) and longer engine life [12]. Nanoparticles have demonstrated enormous potential not only in lubrication purpose but also in various sectors like engine coolant, medicine, diagnostics, cancer therapy, cosmetics, agriculture, gene delivery, antibacterial, etc. due to their better properties enhancing capabilities [13]. Our goal in this study is to compare the heat dissipation of copper oxide (CuO) nanoparticle-based lubricant with a conventional lubricant that is sold commercially. It has been demonstrated that adding CuO nanoparticles to conventional lubricant reduces wear & coefficient of friction (μ) and increases thermal conductivity, especially at optimized concentrations aiding in heat dissipation [9]. To achieve our goal, we blend CuO nanoparticles in conventional lubricant and perform tests in a vehicle engine mainly focusing on parameters related to oil temperature and engine (coolant) temperature. Based on these parameters, heat dissipation capabilities will be evaluated and a comparison will be made on CuO nanoparticle blended lubricant and commercially available conventional lubricant. Some studies have used numerical simulations and theoretical models to determine the possible benefits of nanoparticle-based lubricants in heat dissipation [11]. This study will investigate the use of nanotechnology in lubrication in IC engines and will provide important insights into the feasibility and benefits of adopting nanoparticle-based lubricants.

2. Methodology

2.1 CuO nanoparticle synthesis

The nanoparticle was synthesized at the Nanotechnology laboratory, Department of Applied Sciences and Chemical Engineering, IOE, Pulchowk Campus, Pulchowk, Lalitpur, Nepal. Precipitation method was chosen for the synthesis of CuO nanoparticles as it was the easiest and most effective method [5]. Initially, a beaker was cleaned and an aqueous solution of CuSO4 with a concentration of 0.5M was prepared. 1 ml of glacial acetic acid was added to that aqueous solution prepared in a 200ml beaker. The solution was then heated to 100°C while being constantly stirred in a magnetic stirrer. In a separate 200 ml beaker, 1M of NaOH solution was prepared and dropped into the heated solution until the pH reached 7.The color of the solution changed from green to black as soon as the NaOH was added and a substantial amount of black precipitate was generated. The precipitate was centrifuged and washed with deionized water to remove any residual soluble impurities. The resultant precipitate was then allowed to air dry for 24 hours. The stoichiometry of chemical reactions occurred are:

Concentration (c) = 0.5M

$$\text{Volume (V)} = 200\text{ml} = 0.2\text{L}$$

$$\text{Molecular weight (w)} = 63.55+32.06 + (4*15.99) = 160\text{g}$$

To determine the required amount of solid copper sulfate ($CuSO_4$), the following formula was used:

$$m=c*V*w \quad \text{...... (Eqn.1)}$$

Where, **c** represents the desired concentration, **V** represents the volume required, and **m** represents the molar mass of copper sulfate

$$\therefore m = 0.5*0.2*160=16\text{g}$$

Similarly, for 1M NaOH solution:

$$c = 1\text{M}$$

$$V = 200\text{ml} = 0.2\text{L}$$

$$w = 23+16+1= 40\text{g}$$

$$\therefore m=c*V*w= 1*0.2*40= 8\text{g}$$

Chemical Reaction:

$CuSO_4 + 2NaOH \rightarrow Cu(OH)_2 + Na_2SO_4$

Upon heating, copper hydroxide decomposes and forms copper oxide according to the reaction:

$Cu(OH)_2 \rightarrow CuO + H_2O$

2.2 Characterization of CuO nanoparticles blended lubricant

To evaluate the properties of the synthesized copper oxide (CuO) nanoparticles and their dispersion within the base lubricant, a series of characterization techniques were employed.

2.2.1 Physicochemical property evaluation

To assess the quality and performance characteristics of nano-based lubricants, several key physicochemical properties such as density at 29.5 ^{0}C, kinematic viscosity at 40 ^{0}C and 100 ^{0}C , Viscosity Index, Flash Point, Pour Point were evaluated using standardized ASTM methods at at Nepal Lube Oil Limited, Amlekhgunj, Bara, Nepal.

2.2.2 UV-visible spectroscopy

The presence of CuO nanoparticles in the lubricant was confirmed using UV-Visible spectroscopy at at the Nanotechnology laboratory, Department of Applied Sciences and Chemical Engineering, IOE, Pulchowk Campus.

2.2.3 X-ray diffraction (xrd) analysis

XRD analysis was conducted at NAST (Nepal Academy of Science and Technology), Lalitpur, Nepal to determine the crystalline structure and average particle size of the synthesized CuO nanoparticles. The Scherrer formula is used to estimate the average size of crystallites by measuring the line broadening. The formula is expressed as:

$D = K\lambda/\beta\cos\theta$…….. (Eqn.2)

Where, D represents particle grain size in nm, K represents scherrer constant or shape factor (0.62-2.08), λ represents wavelength of radiation in nm (1.54060Å), β represents FWHM (full width at half maximum) of the reflection peak in radians and θ represents angle at which the peak is located in radians [10].

2.2.4 Measurement of specific heat capacity of oil and rate of heat dissipation

For oils, the specific heat capacity at constant pressure (C_p) has been calculated accurately from the following expression:

$C_P = (0.403 + 0.0008t)*d^{-1/2} * 4.19\ J\ g^{-1}K^{-1}$ [17]…….. (Eqn.3)

The first term in the equation is (0.403 + 0.0008t), represents the temperature-dependent contribution to the specific heat capacity of the substance. As the temperature increases, C_p increases, indicating that more energy is required to raise the temperature of the substance. The second term in the equation is $d^{-1/2}$, which represents the density-dependent contribution to the specific heat capacity of the substance.

Heat transfer rate of both of the lubricants was calculated as below:

For base lubricant:

$$\rho_{base} = 0.8496\ gm/cm^3$$

$$Q_{base} = \rho_{base} * V * C_p * (T_{out} - T_{in})\text{…….. (Eqn.4)}$$

Similarly, for CuO nanoparticle blended lubricant:

$$\rho_{nano} = 0.86\ gm/cm^3$$

$$Q_{nano} = \rho_{nano} * V * C_p * (T_{out} - T_{in})\text{…….. (Eqn.5)}$$

2.3 Blending of CuO nanoparticles in lubricant

For the blending process, 6 liters of TATA MOTORS GENUINE OIL (Diesel Engine Oil CI4+ 15W-40) was used. The CuO nanoparticles was added 0.03% concentration by weight in the lubricant which means, in total 1.452gm of nanoparticles was added to 6 liters (4846.464gm) of engine oil and the further procedure was carried as follows:

1) 0.121gm of CuO nano particles was weighted in the weighing balance.
2) The weighted nanoparticles was mixed in 500ml of lubricant.
3) The mixtures was then transferred to a 200ml beaker for the ultrasonication process.
4) The probe sonicator was then turned on with settings as mentioned below:
   - Pulser: 10 secs and 30 secs (in the ratio of 1:3)
   - Time: 20 minutes
   - Amplitude: 30%
5) The probe was then dipped into the mixture and the probe sonicator was turned "ON".
6) The mixture was then checked every now and then and as the mixture color changed from light brown to dark brown the sample was then taken out. The time observed for blending CuO nanoparticles in 500ml lubricant was 3 hours. Likewise, total 6 litres of lubricant was blended.

2.4 Experimental setup for engine testing

The performance evaluation of the Nano-lubricant was conducted using a TATA 207 DI PICK UP TRUCK which four-wheeler diesel engine under idle conditions. The specifications of the vehicle are in Table 1. The engine was operated for a duration of one hour, with ambient temperature maintained at 18 °C. Both the conventional and nano-lubricants were tested under identical conditions to ensure comparability. Measurements were recorded at five-minute intervals throughout the one-hour testing period. A temperature sensor was inserted into the engine oil sump through the dipstick port to monitor the oil temperature. Similarly, for measuring the engine temperature (coolant temperature), a software named TDS (Tata Diagnostic Software) was used in a digital display laptop, which was connected to the vehicle through a jack port for real-time temperature readings.

Table 1. Specification of test engine vehicle

Engine Type	Tata 3.0L turbocharged engine
Engine Capacity (cc)	2956
Max engine power	65 Hp @ 2800 rpm
Max engine torque	185 Nm @ 1500-2000 rpm
Fuel tank capacity	60L
Top speed (kmph)	100

3. Results and Discussion

3.1 Characterization and analysis of cuo nanoparticles

3.1.1 Physicochemical results

The Table 2 shows the properties of the nanoparticle blended lubricant and base lubricant under similar conditions. The test results shows that the properties of nanoparticle blended lubricant were comparable to base lubricant.

Table 2: Properties of nanoparticle blended lubricant and base lubricant [16]

Characteristics	Method	blended lubricant Value	Value base lubricant
Density at 29.5^{O}C, gm/cm^3	ASTM D 4052	0.86	0.8496
Kinematic Viscosity at 40^{O}C, cSt	ASTM D 445	110.64	103.2
Kinematic Viscosity at100^{O}C, cSt	ASTM D 445	14.682	14.10
Viscosity Index	ASTM D2270	137	140
Flash Point, ^{O}C	ASTM D 92	232	230
Pour Point, ^{O}C	ASTM D 97	-39	-36

3.1.2 UV test results

Study says UV rays ranging from 200-300 nm signify the presence of CuO nanoparticles in the sample [7]. While performing the UV test at the Nanotechnology laboratory, Department of Applied Sciences and Chemical Engineering, IOE, Pulchowk Campus, the peak value was observed at 251.5 nm, which is in the range of 200-300 nm, and it confirms that the sample is CuO nanoparticle [10].

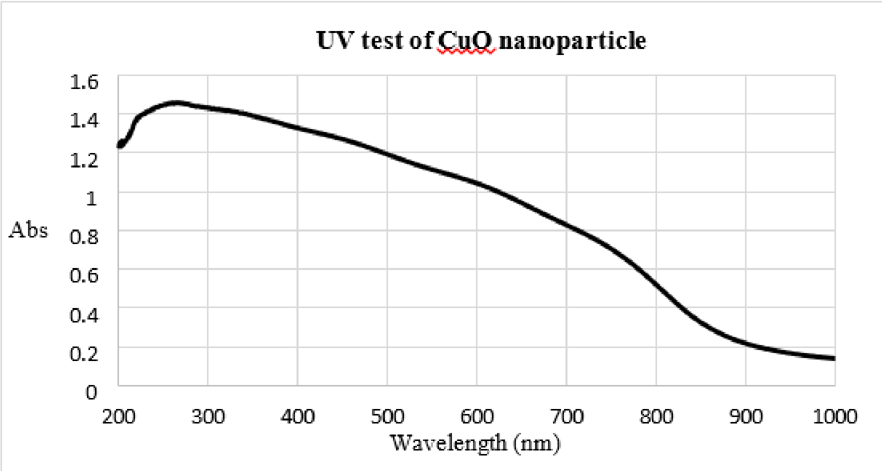

Figure 1. UV test of copper oxide (Absorbance vs Wavelength)

3.1.3 XRD test results

The size of the nanoparticles was found to be 12.25 nm by X-Ray Diffraction Method [3].

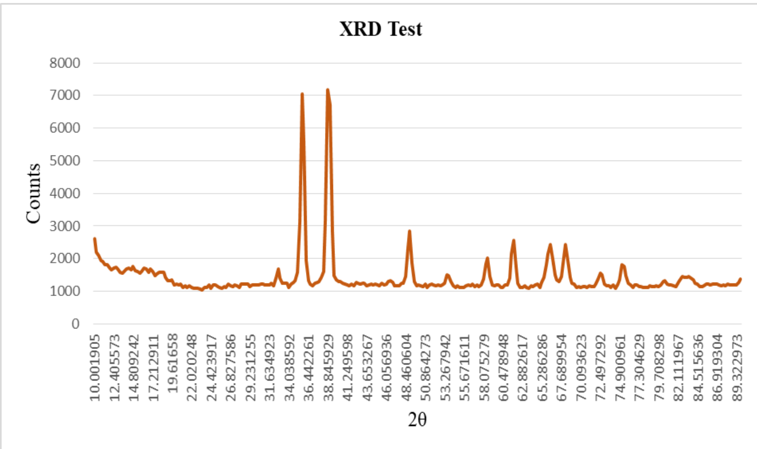

Figure 2: X-Ray Diffraction of Copper Oxide Nanoparticles [15]

Table 3: XRD Data of Copper Oxide Nanoparticles

Nanoparticle	Peaks no.	2θ	FWHM(β)	Grain Size(D)
CuO	Peak 1	32.55604	0.77504	11.02986915
	Peak 2	35.68986	0.68575	12.57112091
	Peak 3	38.89084	0.82195	10.58736949
	Peak 4	49.00051	0.75912	11.87938179
	Peak 5	53.6076	0.74013	12.42175223
	Peak 6	58.42112	0.77403	12.14612581
	Peak 7	61.6948	0.72769	13.13473714
	Peak 8	66.28901	1.21731	8.050947427
	Peak 9	68.13311	0.89006	11.12944495
	Peak 10	72.61921	0.553	18.41442929

Nanoparticle	Peaks no.	2θ	FWHM(β)	Grain Size(D)
	Peak 11	75.1604	0.77084	13.43267611

The average crystallite size of copper oxide nano-particle is determined by taking the average of grain size of all eleven peaks which is calculated as below:

$$D_{avg} = \frac{11.02+12.57+10.58+11.87+12.42+12.14+13.13+8.05+11.12+18.41+13.43}{11} = 12.25 \text{ nm}$$

3.2 Performance result of conventional (base) and nanoparticle blended lubricant

The graph in Figure 3 indicates the more rise in temperature of nano lubricant than that of base lubricant during the same time interval. Similarly, the graph in Figure 4 indicates the drop in engine temperature using nano lubricant than that of when using base lubricant.

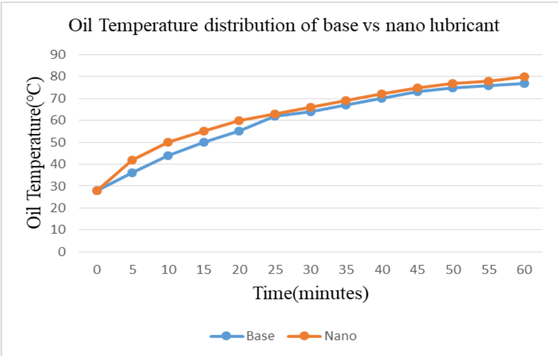

Figure 3: Oil temperature distribution of base vs nano lube over time

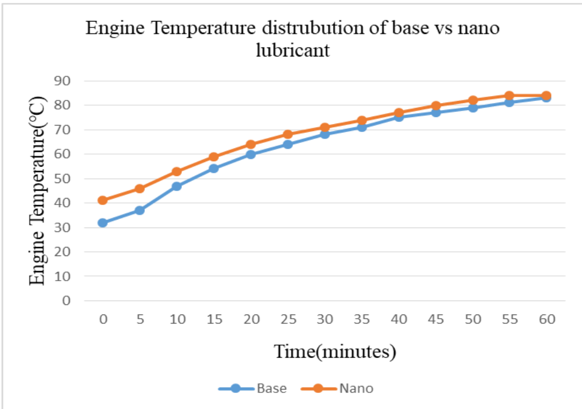

Figure 4: Engine temperature distribution of base vs nano lube over time

The drop in engine temperature using nano lubricant is not observed in Figure 4 because the initial engine temperature using nano lubricant (41°C) during testing was not exactly the same as that of when using base lubricant (32°C). However, following the trend of graph, drop in engine temperature using nano lubricant can be noted.

3.3 Measurement of specific heat capacity of oil

As the density increases, C_P decreases, indicating that less energy is required to raise the temperature of the substance which is shown in table 4 [7].

Table 4: Specific heat capacity of base and nano lube at measured oil temperatures

Time (minutes)	Base Oil Temperature (°C)	Nano Oil Temperature (°C)	C_p of base Oil (JKg^1K^{-1})	C_p of nano Oil (JKg^1K^{-1})
0	28	28	1933.767	1922.04
5	36	42	1962.860	1972.643
10	44	50	1991.953	2001.551
15	50	55	2013.777	2019.62
20	55	60	2031.956	2037.705
25	62	63	2057.412	2048.549
30	64	66	2064.685	2059.392
35	67	69	2075.595	2070.236
40	70	72	2086.505	2081.08
45	73	75	2097.415	2091.923
50	75	77	2104.688	2099.153
55	76	78	2108.325	2102.767
60	77	80	2111.961	2109.996

3.4 Determination of heat dissipation rates

Heat transfer rate of both of the lubricants was calculated using equation 4 and 5 with base= 0.8496 gm/cm^3 for base lubricant and ρ_{nano} = 0.86 gm/cm^3 for CuO nanoparticle blended lubricant and volume, V = 6 L = $0.006m^3$.The heat dissipation for both lubricant was calculated on each time interval and a graph were drawn which is shown in the figure 5.

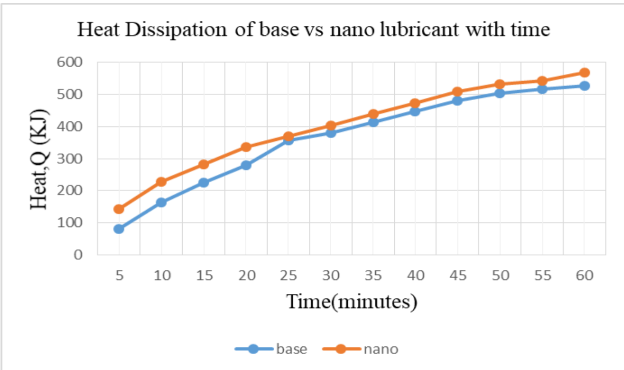

Figure 5: Heat dissipation of base vs nano lubricant with time

Figure 5 shows the heat dissipation curve which demonstrate that adding copper oxide nanoparticles to the base lubricant causes the lubricant to absorb more heat from the engine to the oil sump. Simultaneously, the cooling effect increases in response to an increase in heat dissipation by the dropping of engine temperature (coolant temperature). The temperature variation between a base lubricant and nano lubricant are summarized in table 5:

Table 5: Rise in oil and engine temperature of base lubricant during testing 1 hour

	Oil Temperature		Engine Temperature	
Base lubricant	0 min	60 min	0 min	60 min
	28°C	77°C	32°C	83°C

Rise in Temperature	49℃	51℃

Table 6: Rise in oil and engine temperature of nano lubricant during testing 1 hour

	Oil Temperature		Engine Temperature	
Nano-based lubricant	0 min	60 min	0 min	60 min
	28℃	80℃	41℃	84℃
Rise in Temperature		52℃	43℃	

The Table 5 shows the rise in oil temperature and engine temperature of base lubricant, i.e. 49 ℃ and 51℃ respectively. Similarly, the Table 6 shows the rise in oil temperature and engine temperature as 52℃ and 43℃ respectively in nano based lubricant. From this observation, it was cleared that the rise in oil temperature of nano based lubricant is more, meaning more heat was absorbed by the lubricant which resulted in cooling of the engine, as the rise in engine temperature is less in the nano based lubricant.

4. Conclusion

In summary, the goal of the experimental study was to better understand how nanoparticle based lubricant in internal combustion engines dissipates heat. The goal along with the preparation of nanoparticles was to improve heat dissipation, which would improve engine performance when added to lubricant blends. The findings shows that the engine oil temperature increased from 49 °C with the conventional lubricant to 52 °C when utilizing the nano-based lubricant. This 3 °C rise in temperature suggests an enhancement in the thermal conductivity of the lubricant due to the inclusion of nanoparticles.

The increase in oil temperature can be attributed to the improved heat transfer properties of nano-lubricants. This suggests that the nanotechnology may be used to optimize IC engine lubricating system, increasing the engine's longevity and efficiency. The study's conclusions add to the expanding body of information about the applications of nanoparticles in automotive engineering and emphasize the significance of more research in this field for the development of effective and sustainable transportation solutions.

5. Limitations

However, some of the limitations has been observed during the research regarding the use of nanoparticle based lubricant in IC engine which are:

1) Nanoparticle blended lubricants can be more expensive to produce than conventional base lubricants.
2) Nanoparticles have a tendency to agglomerate or clump together, which can affect their dispersion in the lubricant and may corrode the parts on reaction.
3) The addition of nanoparticle to lubricants can sometimes increase or decrease their viscosity, which may not be desirable in all engine applications.
4) Incorporating nanoparticles into lubricants requires specialized manufacturing and handling processes to ensure uniform dispersion and stability of the nanoparticles.

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