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Analysis of Heat Transfer Rate on Copper Oxide - Nano Fluid Based Lubricants

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Abstract
Nanoparticles shows unique behaviors which make them suitable to improve the performance of modern lubricants by increasing heat dissipation rate in an engine. The increase in heat dissipation rate allow engine to reduce the cooling load. It is also shown that the rate of heat transfer enhances by adding Copper Oxide in engine oil which improved its lubrication properties regardless of not any degradation in the major frictional properties of lubricates as well. The purpose of present research is to add Copper Oxide Nanoparticles and enhance the thermo-physical properties like Viscosity, Pour Point, Flash point which are neared at 0.02,0.2 and 0.5% by weight of 15W40 Commercial engine oil and improve heat dissipation from the engine which is shown by the performance testing result and comparison between the normal and copper oxide nanoparticle based engine oil and found that the average heat dissipation on Copper Oxide based Nano particle is higher than the normal base oil.

Keywords
Nano lubricants, Experimental study, Heat transfer, Thermal conductivity

1. Introduction

Nano additives on the lubrication is huge growing filed and widely used by many sciences like chemical engineering, Fluid dynamics, geology and biology, its growing research filed as many researchers concluded the Nano sloid mixes with liquid properly and shows the solid behavior on liquid flow domain which will dramatically changes the fluid properties. In automotive industry lubrication is one of the major functions to be used as it enhances machine life, remove away the heat form the moving mechanical comments, so the many researchers have been carried out to improve the lubrication property of lubricants. Different research work has been listed here about the use of different nanoparticles on base fluid to enhance the thermos physical properties of Nano fluids and ultimately improving the heat dissipation rate from the engine.

The internal combustion engine is a crucial power source for vehicles, converting thermal energy from fuel combustion into mechanical energy to drive them. The operational reliability of the engine is vital for safe vehicle operation. The thermal load and lubrication friction of the piston set-cylinder liner, which are important friction pairs, directly affect the engine's reliability and durability, influencing its power performance, efficiency, and safety. Operating conditions for the piston set-cylinder liner are harsh, involving high temperature, pressure, and impact load. The heat load generated by the circulating and transient high-temperature and high-pressure gas exposes the piston set-cylinder liner to significant heat, which can cause ablation, deformation, or damage to the material's strength and hardness. Moreover, the lubricating oil film may be destroyed or even coked, leading to severe wear and failure. Therefore, research into heat transfer and lubrication friction of the piston set-cylinder liner is a popular topic of interest. Numerous studies have investigated lubricant thermophysical properties and adding nanoparticles to enhance them, which is an ongoing research field. By selecting suitable nanoparticles with appropriate concentrations in the base lubricant, the heat dissipation rate from the engine can be improved.

A test carried out by V. Sajith et.al. prepared nanoparticle mixture of Al_2O_3 and CuO at solid concentration of up to 0.2% in between $30-70^oC$ The observed trend in the kinematic viscosity of the lubricating oil indicated a slight increase up to a dosage of 0.02% volume fraction of nanoparticles, followed by a subsequent decrease upon further increase in the dosage level., this may be due to the agglomeration of the Nano fluids which leads to decrease of the Viscosity of the oil [1]. A study was conducted to investigate the thermophysical properties of engine oil using TiO_2. The results of the study indicated that the use of nanofluids with high thermal conductivity resulted in more effective heat transfer. Variation of heat transfer in the evaporator with the use of both mineral oil and Nano fluid [2]. Ahmadi et.al. conducted an experiment by addition of Multiwall Carbon Nan tubes with thermal oil at concentration of 0.1-0.5 % by weight and found Thermal conductivity enhancement of 22.7 % [2]. Thermal and rheological properties of oil-based Nano fluids from different carbon nanostructures studied using different CNTs Nano fluids on base oil SAW 20W50 at concentration of 0.1-0.2% over the temperature range of $40-100^oC$ and found that Enhancement in thermal conductivity and flash point, but no considerable enhancement in viscosity.The effect of temperature and solid concentration on dynamic viscosity of MWCNT-MgO was experimentally carried out at the concentration range of 0.2-2% by Wt. over temperature range of $25-51^oC$ and observed Newtonian fluid with the maximum viscosity enhancement of 65 %at the temperature of 40 °C and a solid concentration of 2 % and the maximum enhancement in thermal conductivity of utilized Nano fluid is approximately 62 % which took place at the solid concentration of 2 % and temperature of $50C$ [3]. A test carried out by Hemmat et. al. concluded after the addition of Al_2O_3

Nano partilces at concentration of 0.25 – 2 % by Weight of the based fluid over operating temperature of $5-65^0C$ shows Newtonian fluid with the maximum viscosity enhancement of 132 %,viscosity of the Nano fluid increases with the solid volume fraction. Moreover, it has been found that with increasing temperature, the viscosity of Nano fluids decreases, and it was more tangible at the lower temperatures [4]. Non-Newtonian power-law behavior of TiO_2/SAE 50 Nano lubricants was used with thermal base oil to analyze the pumping power and observed experimentally over temperature range of $25-50^oC$ with concentration of 0.125-1.5% and found that the dispersion of nanoparticles in the lubricant resulted in overall performance enhancement of compressor. The working was found to be smoother and consuming lower power [5].

A study was conducted to synthesize Cu-engine oil nanofluid and investigate its stability, thermal conductivity, and viscosity over a temperature range of $40-100^oC$. The solid concentration used in the study ranged from 0.2% to 1% and found that the flow regime become Newtonian fluid with maximum thermal conductivity and viscosity enhancement of 49 % and 37% [6] .An Experimental Investigation on Heat Transfer Capability of $Mg(OH)_2$ / MWCNT-Engine Oil Hybrid Nano-Lubricant Adopted as an Automotive Coolant and Lubricant over temperature range of $25-60^oC$with solid concentration of 0.5-2% and found thermal conductivity enhancement of 50% (al A. e., 2017).A study was conducted to investigate the rheological behavior of MWCNTs/ZnO-SAE40 hybrid Nano-lubricants at different solid volume fractions and temperatures ranging from $25-60^0C$. The solid concentration used in the study ranged from 0.5-1%. The results revealed that the flow regime of the Nano-lubricant was Newtonian, and the maximum viscosity enhancement was observed at a solid concentration of 1% and a temperature of 40ºC, with an increase of 33.3%[7].

An experimental and theoretical investigation was conducted to evaluate the heat transfer efficiency of Al_2O_3-MWCNT/thermal oil hybrid nanofluid as a cooling fluid in thermal and energy management applications. The results showed that the thermal conductivity of the nanofluid increased with an increase in temperature and solid concentration in both laminar and turbulent flow regimes (up to 1% solid concentration). The maximum enhancement in thermal conductivity was found to be 45% [8]. When the temperature was varied from $20-70^oC$, the thermal conductivity of Nano graphene lubricants exhibited a decrease of 1.33-7.62% with increasing mass concentration. The study also found that the viscosity of the graphene-based lubricants increased with an increase in the concentration of graphene [9].

2. Experimental Materials and Methods

The methodology followed for the Nano additives based lubricants with different concentration of copper oxide Nano particles over different temperature ranges on a IC engine is schematically shown below and results of different heat dissipation parameter will be analyzed on different operating conditions.

2.1 Synthesis of Copper Oxide nanoparticles

The nanoparticle was synthesis on RECAST (Research center for applied science and technology) TU, Central Department Balkhu Kathmandu. CUO Nano particles is prepared by Sol-Gel Method, which is common for the metal oxides, it is carried out on different steps.

2.2 Procedure for the synthesis of Copper Oxide Nanoparticles

These are the step followed during the synthesis of nanoparticles by sol-gel method and very clear precipitate which clearly separated from rest of the solution which conforms clear the formation of copper oxide nanoparticles as per attached figure below.

- A round bottom flask was cleaned and used to prepare an aqueous solution of $CuSO_4$ with a concentration of 0.5M.
- In a 200 ml beaker, 1 ml of glacial acetic acid was added to the aqueous solution prepared in a cleaned round bottom flask. The solution was then heated to 100°C with constant stirring. A 0.5M NaOH solution was prepared in a separate 200 ml solution, and it was added dropwise to the heated solution until the pH reached 7. As soon as the NaOH was added, the color of the solution changed from green to black, and a large amount of black precipitate was immediately formed.
- After formation, the precipitate was centrifuged and washed 3-4 times with deionized water. The resulting precipitate was then allowed to air dry for a period of 24 hours.

The calculation and chemical reaction are as follows: -

$$Molecularweight, M = 63.55 + 32.06 + (4 * 15.99) = 160g$$

$$Concentration = c = 0.5M$$

$$Volume = V = 1L$$

To determine the required amount of solid copper sulfate pentahydrate, the following formula was used:

$$m = c * V * M$$

, where c represents the desired concentration, V represents the volume required, and M represents the molar mass of copper sulfate pentahydrate.

$$m = 0.5 * 1 * 160 = 80g$$

$$CuSO_4(0.5M) + 2NaOH \rightarrow Cu(OH)_2 + Na_2SO_4$$

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

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

The CuO Nanoparticles were prepared by precipitation method using Copper Sulphate and sodium hydroxide as precursors.

2.3 Characterization of Nanoparticle

The synthesized copper oxide nanoparticles were characterized using X-Rayed Diffraction(XRD) at angle of rotation of $20-40^0$, the picks and valley of intensity bar is calculated at different angles and maximum values were taken for the size determination as per below formula. The Scherrer formula can be used to estimate the average size of crystallites by measuring the line broadening. The formula is expressed as

$$D = K\lambda/\beta cos\theta$$

where D represents the average particle size, λ represents the wavelength of radiation, β represents the FWHM(full width at half maximum) of the reflection peak that has the same maximum intensity in the diffraction pattern, and θ represents the angle at which the peak is located. The Scherrer constant (K) is included in the formula to account for the shape of the particle, with a value of 0.9 commonly used for spherical crystals. By applying the Scherrer formula, the obtained size represents the average or apparent particle size for the material.

2.4 Characterization of Nano Lubricant

Before characterizing the Nano lube, we prepared the reference data's of base oil only to ensure the parameters range and comparing the data's, the base oil characterization shown below in table.

Table 1: Typical Physio-Chemical Data: MAK FLEET CI4+ 15W-40 (Product Data Sheet)

Characteristics	Method	Value
SAE Grade	SAE J300	15W-40
Color	Visual	Brown
Appearance	Visual	Clear
Density at $29.5^oC, g/cc$	ASTM D1298	0.865
Kinematic Viscosity at 40^oC, cSt	ASTM D445	103.5
Kinematic Viscosity at 100^oC, cSt	ASTM D445	14.2
Viscosity Index	ASTM D2270	140
Copper Corrosion 100^oC, 3 hrs.	ASTM D130	1a
Flash Point ^0C	ASTM D92	232
Pour Point ^{0} C	ASTM D97	-24

After dispersing nanoparticle completely with base oil the Nano lube prepared at different solid concentration by weight of 0.02 and 0.5% by weight, it is subjected to test for the measurement of density, viscosity, thermal conductivity, flash point and pour point and the obtained at Nepal Oil Co-corporation and the results are shown in table below.

Table 2: Characterization of Different sample of Nano lube by Nepal Oil Co-operation

Characteristics	Method	Value
		CuO Nano fluid Based Oil
SAE Grade	SAE J300	15W-40 with CuO Blend
Color	Visual	Grey
Appearance	Visual	Clear
Density $at 29.5C, g/cc$	ASTM 01298	0.905
Kinematic Viscositv $at 40^0C, cSt$	ASTM 0445	107.44
Pour Point ^{0}c	ASTM 097	-12

2.5 Performance Testing of the Lubricates on an IC Engine

The performance testing is carrier out in two steps, first one is the engine is started under the idle condition using SAE 15W40 TATA CI4 Engine oil and the general vehicles parameters is calculated using the TDS-XENON Yodha /Compact BSIV-EMS BS-4 and the mentioned data were measured Data measured at time interval of 5min. and similarly the oil temperature is measured by pouring the temperature sensor on mobile gauge guide and the value read by the device called smoke meter.

The second test is carried out by using prepared Nano lube and the vehicle parameters are calculated using previous used diagnosis tool for base oil and Smoke meter device for measuring different parameters.

3. Results and Discussion

3.1 Nanoparticle Synthesis

The required specification of nanoparticle has been prepared with its purity and specified physical properties by sol-gel method of synthesis, and then X-Rayed diffraction conducted for the characterization of size of prepared copper Oxide nanoparticle. The result from the XRD is shown below.

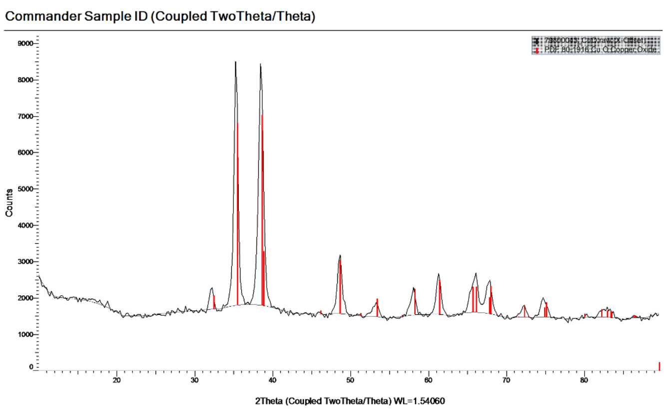

Figure 1: X-Ray Diffraction of Copper Oxide Nanoparticles (NAST)

The data's of XRD are listed in table 3:

Table 3: XRD Data of Copper Oxide Nanoparticle

Nanoparticles	Xc	FWHM	Grain Size
	32.55604	0.77504	11.02986915
	35.68986	0.68575	12.57112091
	38.89084	0.82195	10.58736949
	49.00051	0.75912	11.87938179
	53.6076	0.74013	12.42175223
CuO	58.42112	0.77403	12.14612581
	61.6948	0.72769	13.13473714
	66.28901	1.21731	8.050947427
	68.13311	0.89006	11.12944495
	72.61921	0.553	18.41442929
	75.1604	0.77084	13.43267611

The XRD data concluded the formation of pure and uniform Copper Oxide Nano particle of copper oxide. This is calculated from XRD Curve using above discussed Scherer formula with wavelength of imposed X- Ray 1.315Å.

3.2 Nano lubricants Preparation

The intact mixing of copper oxide nanoparticles on the base fluid was achieved and it is eligible for the further test on the engine with all its physical and chemical as well as thermal criteria reached and found improvement on thermo physical parameter like viscosity, and pour point after addition of the nanoparticle on the base oil as shown.

Table 4: Some Measured Thermo physical Physical Properties SAE 15W40 TATA CI4 and prepared Nano lube for Engine Testing

Characteristics	Method	Value	
		Normal Oil	CuO Nano fluid Based Oil
SAE Grade	SAE J300	15W-40	15W-40 with CuO Blend
Color	Visual	Brown	Grey
Appearance	Visual	Clear	Clear
Density at 29.5°C,g/cc	ASTM 01298	0.865	0.905
Kinematic Viscositv $at 40^0 C, cSt$	ASTM 0445	103.5	107.44
Pour Point,^{0}c	ASTM 097	-24	-12

3.3 Performance Testing of the Lubricants on an IC Engine

The engine performance parameters were calculated first by using normal lubricants and the temperature of the oil inside the oil sump is measured and it is compared with the same setup using the Copper oxide-based Nano additives resulting in the improvement of all vehicle parameters like Oil Temperature, engine operating temperature.

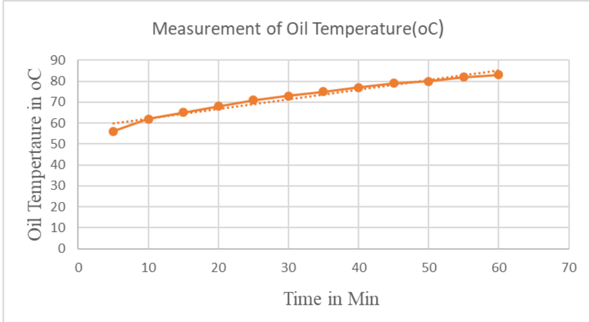

Figure 2: Oil Temperature Distribution Using Normal Oil

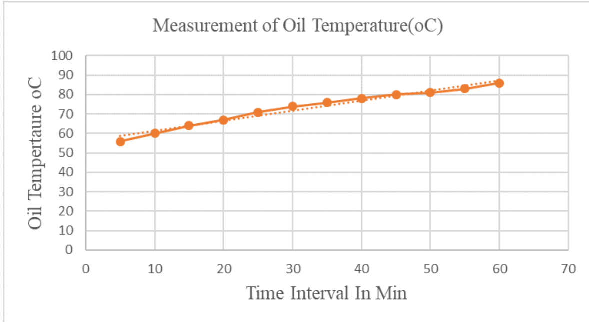

Figure 3: Oil Temperature Distribution Using Copper Oxide based Normal Oil

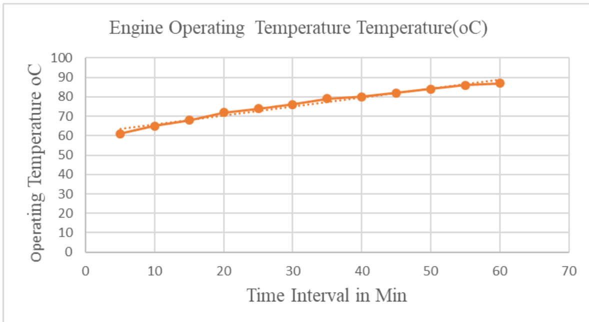

Figure 4: Engine Operating Temperature Distribution Using Normal Oil

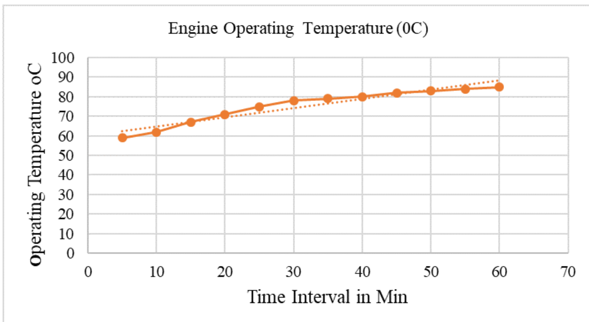

Figure 5: Engine Operating Temperature Distribution Using Copper Oxide based Normal Oil

The above curves shows there is significant increase in oil temperature after the addition of copper oxide nanoparticles on the base oil which shows the oil carries away more heat from the engine to the oil sump , this conforms higher heat dissipation after the addition of copper oxide nanoparicle on the normal lubricant.

After the increase on heat dissipation the cooling effect is increased, this is confirmed by the deacrese in the engine operating temperature as shown on the above engine opertaing temperature curves.

4. Conclusion

The physical – chemical properties of the lubricants were improved after the addition of the copper oxide nanoparticles. Nano particle thus enhances the thermo physical property which results in the improvement on the heat dissipation from the lubricating oil , shown by the performance testing curves , it found that the addition of nanopartcile on lubricating oil increases heat dissipation which improves the engine cooling effect and also improves the life of the engine components .

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