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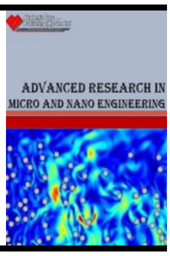

A Comprehensive Review on Tribological Behaviour of Hybrid Nanocellulose-CuO as Nanolubricant for Piston Ring Cylinder Liner Application

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ABSTRACT

Friction coefficient and wear rate are crucial performance for the development of nanolubricants, which are of great significance for realizing energy conservation and prolonging service life of mechanical components. Herein, this review systematically describes the progress on nanocellulose (CNC) and Copper (II) oxide (CuO) as effective nanoparticles for developments of nanolubricant as oil additives for improving the anti-friction and wear resistant for piston ring-cylinder liner contact. Additionally, we point out several problems existing in the applications of CuO and CNC additives propose the possible solutions. Finally, the research prospects of CNC-CuO in the field of tribology are prospected.

1. Introduction

Lubricants are essential in determining the lifespan of a mechanical system and energy saving. Lubricants are generally used for lubrication, cooling, and sealing. It adheres to the moving surface areas, forming fluid films that split the surfaces of moving components, carrying away wear particles and heat from the system. Lubricants are extensively produced and contain various additives and base oils. The base oil is commonly categorized as biological, synthetic, and mineral oils [1]. Additives are utilized to improve overall lubrication performance, such as anti-friction, anti-wear, anti-corrosion, viscosity stabilizer, clotting, film-forming, etc. [2]. Chemical additives, such as phosphorous, chlorine, and sulphur enhance lubrication efficiency by creating a sacrificial chemical layer. But, these additives lead to undesirable environmental impacts [3]. Recent studies have revealed the capability of nanoparticles as a potential additive for lubricants [1]. Nanoparticle additives are categorised into seven categories based on chemical component properties such as nanocomposite, rare earth compounds, sulphide, carbon, metal, metal oxide, and many others [4]. Nanolubricant displays substantially changed tribological properties [5-8]. The primary use of lubricants is to preserve the quality and minimize the wear of surfaces [1]. The tribological properties

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of base lubricants are enhanced with the dispersed nanoparticles the utilizing a variety of mechanisms such as the polishing effect [8,9], tribofilm formation [10], ball-bearing effect [8,11], and mending effect [12]. Tao and Kang [8] stated that the paraffin oil distributed with diamond nanoparticles reaching the rubbing surfaces transforms rolling motion from sliding motion through serving as a ball bearing. Through scanning tunnelling microscopy, Liu *et al.,* [12] detected the wear scar with the Cu nanoparticles deposition, which is referred to as a mending effect. Zhou *et al.,* [10] indicated that Cu nanoparticles interact with friction pair surfaces to create tribofilms, which mainly improve the anti-wear capability of friction surfaces. Tang and Li [9] reported that the surface polishing effect that creates microplates with exceptionally smooth surfaces and a nearly uniform height reduces surface roughness. Lee *et al.,* [13] utilized graphite nanoparticles at a 0.5% volume fraction and recorded a 24% reduction in mineral oil friction coefficient. Chang *et al.,* [14], using a 2% volume fraction of graphite nanoparticles, identified a 60% decrease in the frictional coefficient of lithium grease. Kimura *et al.,* [15] recorded a 75% decrease in wear using boron nitride (BN) nanoparticles at an 8% volume fraction paraffin mineral oils. The BN sticks to surfaces and marginally raises friction; however substantially lowers the wear. Ma *et al.,* [16] found adverse wear in machine oil with ZrO_2 nanoparticles due to the high deposition rate relative to the wear rate. Thottackkad, Rajendrakumar [17] recorded that CeO_2 nanoparticles exhibit the most prominent improvement (17%) in coconut oil wear than engine oil with paraffin oil. The researchers also found that the specific wear rate declines initially to a minimal point and then grows with addition in the nanoparticles volume fraction.

2. Coefficient of Friction and Anti-Wear Properties of Nanolubricants

Nanoparticles dispersion in base lubricants creates important adjustments in anti-wear and coefficient of friction properties. The nanoparticles lubrication mechanism as consists as mentioned above of surface polishing, patching, mending, tribofilm formation, and rolling effect [8-12,22]. The following segment discussed the adjustment of the nanoparticle’s dispersion with base lubricant in anti-wear and coefficient of friction properties.

2.1 Coefficient of Friction of Nanolubricants

One of the critical factors for the lubricant's performance is the coefficient of friction. Graphite nanoparticles at 0.5% volume fraction enriched in gear oil (super gear oil EP220) noted a 24% reduction in coefficient of friction reported by [13]. The reduction of friction between surfaces is due to the graphite nanoparticles functioning as ball-bearing spacers between friction surfaces. *Chang et al.,* [14] dispersed TiO_2 nanoparticles at a 1% weight fraction with lithium grease and observed a 40% reduction in coefficient of friction. This is due to the spherical nanoparticles that promoted rolling action, which is the same as the micro bearing action. Mineral oil (SN650) enriched with Cu nanoparticles of 0.15% weight fraction and observed a decrease in coefficient of friction (34%) as reported by Wang *et al.,* [18]. The potential cause for these decreases might be owing to the development of self-repairing film in the base oil that splits the friction surfaces. Dispersion of 0.5 g Cu nanoparticles in 100 ml SAE 10 mineral oil was observed with 49% lessening in the coefficient of friction owing to the metallic nanoparticle layer formation as stated by Padgurskas *et al.,* [19]. *Wu et al.,* [20] dispersed engine oil (SAE30 LB51153) with CuO nanoparticles at 0.1% volume fraction reported 18.4% drop in the coefficient of friction, owing to the rolling effect via spherical nanoparticles. The variant of friction coefficient for various nanolubricants is shown Figure 1. It was found that extensive coefficient of friction property was investigated using variations of nanolubricants. In the majority of the situations, it is observed that there is an improvement in the coefficient of friction. The variant of the frictional coefficient with dispersion of nanoparticles is summarized in Table 1.

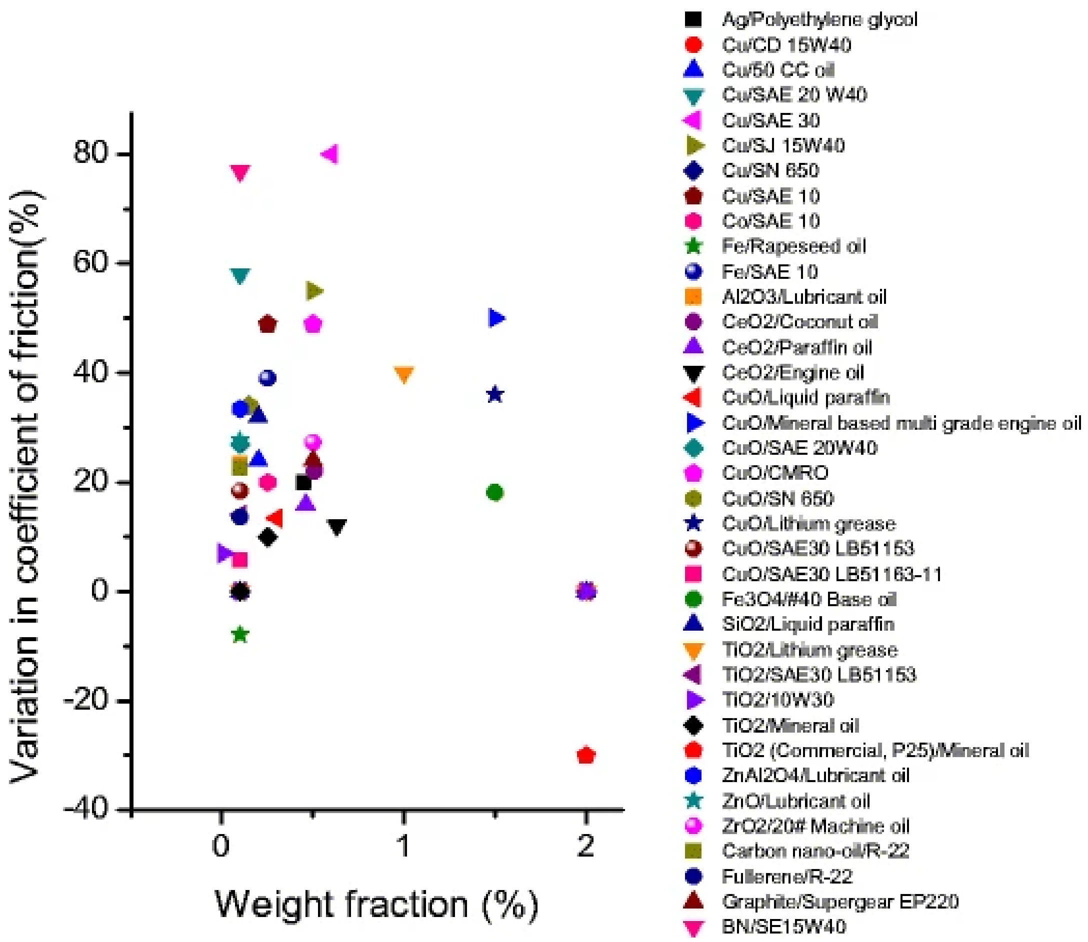

Fig. 1. Variant in the coefficient of friction for nanolubricant. Source: [13,14,16-38]

Table 1
Frictional coefficient summary of nanolubricants

Nanoparticles	Size (nm)	Base lubricants	Concentration	Approx. variation (%)	References
Ag	7	Polyethylene glycol	0.45 wt.%	20 (Decrease)	[23]
Al_2O_3	78	Lubricating oil	0.1 wt.%	23.92(Decrease for the thrust-ring test)	[39]
Al_2O_3	78	Lubricating oil	0.1 wt.%	17.61 (Decrease for four-ball test)	[39]
Al_2O_3	95	Lubricant oil	0.1 wt.%	23.4* (Decrease)	[30]
BN	120	SE15W40	0.1 wt.%	76.9 (Decrease)	[22]
Boric acid	< 50	SAE 15 W40	1:10 vol. proportion	8*(Decrease)	[40]
Boric acid	< 50	SAE 90	3:10 vol. proportion	13*(Decrease)	[40]
Carbon nano-oil	-	R-22	0.1 wt.%	22.7* (Decrease)	[37]
Cu	< 20	SAE 15 W40	1:10 vol. proportion	6*(Decrease)	[40]
Cu	40	SAE 20 W40	0.1 wt.%	58 (Decrease in frictional force)	[26]
Cu	3*	SJ 15 W40	0.5 wt.%	55 (Decrease)	[28]
Cu	-	SAE 30	0.6 wt.%	80* (Decrease)	[27]

Cu	< 20	SAE 90	3:10 vol. proportion	33*(Decrease)	[40]
Cu	-	SN 650	0.15 wt.%	34 (Decrease)	[18]
CuO	40	CMRO	0.5 wt.%	49 (Lesser than CMRO)	[32]

2.2 Wear for Nanolubricant

The durability of the equipment is relying on the anti-wear properties of nanolubricants. *Sia et al.,* [41] using mineral oil (Ecocut HSG 905) with SiO_2 nanoparticles of 0.5% weight fraction indicated significant lessening in wear. This is owing to the deposition of nanoparticles in surface grooves. Nevertheless, degradation in behaviour is detected owing to the collision of nanoparticles when using 0.8% weight fraction of SiO_2 nanoparticles, which contribute to fewer nanoparticles deposition. Chang *et al.,* [14] dispersed lithium grease with CuO nanoparticles at 2% weight fraction and noticed a 60% reduction in wear. A protective tribofilm was formed as nanoparticles of CuO penetrated into the rubbing surfaces asperities. Zhang *et al.,* [28] dispersed SJ 15 W/40 engine oil with Cu nanoparticles at 0.5% weight fraction, and observed 90% reduction in wear. In the beginning, it was observed that the rubbing process lead the tribolayer of Cu nanoparticles between the rubbing surfaces is desorbed. However, Cu becomes fastened on the shearing surface simply through melting as well as welding owing to the sufficient energy on the new wear surface. The reduction for wear loss of tribo-pairs is contributed by the in-situ protective layer formation.

Wang *et al.,* [18] dispersed mineral oil (SN650) with Cu nanoparticles at 0.15% weight fraction and led to decrease in width of the worn trace by 32% owing to the development of the self-repairing film. Padgurskas *et al.,* [19] performed a set of the investigation by using 100 ml of SAE 10 mineral oil with 0.5 g of Co, Cu, and Fe nanoparticles as well as their mixtures. It was discovered that a minimum lessening of wear about 11%, 47%, and 23% with nanoparticles of Co, Cu, and Fe, respectively Wu *et al.,* [20] dispersed base oil (SAE30 LB51163–11) using CuO nanoparticles at 0.1% volume fraction and detected lessening in the depth of worn scar by 78.8%. This reduction occurred as the worn surface is deposited with CuO nanoparticles. The anti-wear properties for various nanolubricants are shown in Figure 2. The variant in wear with the dispersion of nanoparticles is summarized in Table 2.

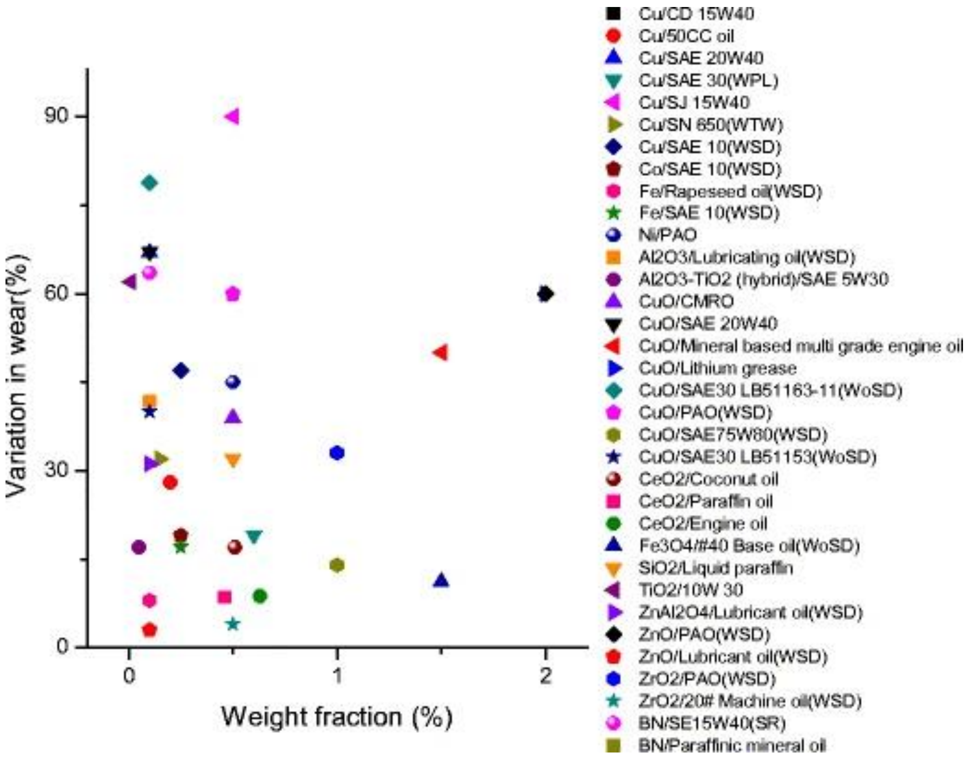

Fig. 2. Variant in wear for various nanolubricants. where SR-Surface roughness, WoSD-worn scar depth, WSD-wear scar diameter, WTW-wear trace width, and WPL-wear path length. Source: [14-22,24-30,32-35,39,42-45]

Table 2
Wear summary of nanolubricants

Nanoparticles	Size (nm)	Base lubricants	Concentration	Approx. variation (%)	References
CeO_2	30– 150	Engine oil	0.63 wt.%	8.7(Decrease)	[17]
CeO_2	30– 150	Paraffin oil	0.46 wt.%	8.5(Decrease)	[17]
Co	50– 80	SAE 10	0.25 wt.%	19*(Decrease in wear scar dia)	[19]
Cu	20	50CC oil	0.2 wt.%	28 (Decrease)	[25]
Cu	50	CD 15 W40	7.5 wt.%	35 (Decrease)	[24]
Cu	50– 80	SAE 10	0.25 wt.%	47 (Decrease in wear scar dia)	[19]
Cu	40	SAE 20 W40	0.1 wt.%	67 (Decrease)	[26]
Cu	-	SAE 30	0.6 wt.%	19* (wear path length decrease)	[27]
Cu	-	SJ 15 W40	0.5 wt.%	90(Decrease)	[28]
Cu	3*	SN 650	0.15 wt.%	32(Decrease in wear trace width)	[18]
CuO	40	CMRO	0.5 wt.%	39 (lesser than CMRO)	[32]
Ag	7	Polyethylene glycol	0.45 wt.%	*(Decrease)	[23]
Al_2O_3	95	Lubricant oil	0.1 wt.%	7* (Decrease in wear scar dia)	[30]
Al_2O_3	78	Lubricating oil	0.1 wt.%	41.75 (Decrease for four ball-test)	[39]
BN	2.85µm	Paraffinic mineral oil	8 wt.%	75 (Decrease)	[15]
BN	120	SE15W40	0.1 wt.%	63.5(Decrease in surface roughness)	[22]
CeF_3	25	500SN	0.5vol. %	6.5 (Decrease in wear scar dia)	[46]
CeO_2	30– 150	Coconut oil	0.51 wt.%	17 (Decrease)	[17]
Ag	7	Polyethylene glycol	0.45 wt.%	*(Decrease)	[23]

According to the widely available literature studies, the research fraction for various nanolubricants properties is presented in Figure 3. It has been discovered that anti-wear properties and friction coefficient of nanolubricants are broadly explored, which also shows the optimistic approach of research society towards potential nanoparticle additives. On the other hand, there is a limited experimental finding for specific heat and density of nanolubricants has been reported. Moreover, well recognized mathematical models are extensively utilized for estimation invariant of these by variable volume fraction of nanoparticles.

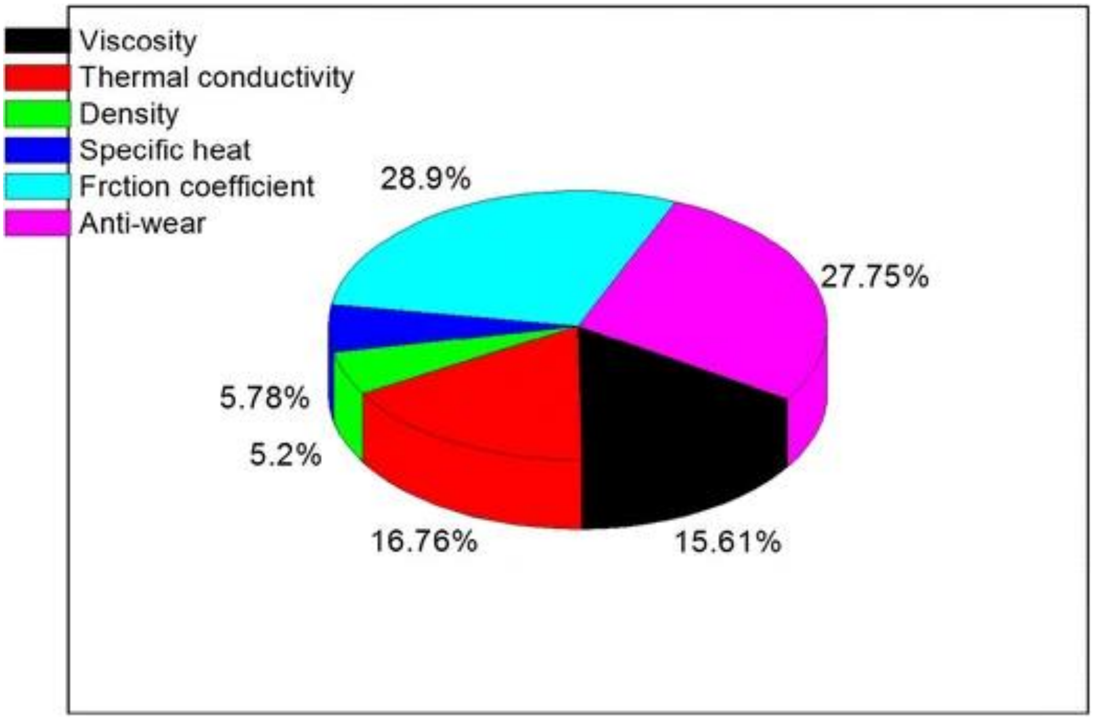

Fig. 3. Research fractions for various properties of nanolubricant. Source: [47]

3. Addition of Copper (Cu) and Copper Oxide (CuO) and Nanocellulose (CNC) Nanoparticle Additives in Engine Oil

3.1 Addition of Copper (Cu) and Copper Oxide (CuO)

Suryawanshi *et al.,* [48] have examined the tribological properties effect of engine oil 20W40 with copper oxide (CuO) nanoparticles. In the tests, the spherical shape with the grain size of 25–55 nm of CuO nanoparticles had been utilized. The engine oil with various concentrations of 0.2, 0.5, 0.75, and 1 wt. % CuO nanoparticles have been prepared as samples. The investigation produced very stable CuO nanoparticles dispersibility in organic solvents which synthesized with an oleic acid surface modifier. The observed findings revealed that engine oil dispersed with CuO nanoparticles help in the reduction of coefficient of friction by 24% and 53% at 0.5 wt. % concentrations, respectively than the standard engine oil without CuO nanoparticles addition. It also resulted in anti-wear properties and a good friction reduction. The investigational testing was performed by Battez *et al.,* [49] for the reduction of wear and friction using dispersion samples of ZnO, ZrO_2, and CuO nanoparticles with engine oil. Experiments were prepared through a total distance of 3.066 m, reciprocating the sliding speed of 2 m/s, and under a load of 165 N. Once completing the wear testing, scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS) were utilized for analysis of wear surfaces. The ultrasonic mixing with duration of 2 min has been utilized to prepare 0.5–2.0 wt. % concentration of nanoparticle. The grain sizes of nanoparticle were constant at 20–30 nm for ZrO_2, 30–50 nm for CuO, and 20 nm for ZnO, respectively. The overall best tribological behaviour indicates a concentration of 0.5% of ZrO_2 and ZnO presenting wear reduction and high friction values. However, the 2.0 wt. % concentration of CuO nanoparticle suspensions had the lowest wear and the highest friction coefficient.

Ahmadi *et al.,* [50] aims to investigate the effects of SAE 20W50 engine oil dispersed with CuO nanoparticles on tribology properties such as thermal conductivity coefficient, flash point, pour point, and viscosity. The copper oxide nanoparticles with grain sizes of smaller than 100 nm are used to different prepared concentrations of samples at 0.1, 0.2, and 0.5 wt.%. These factors were examined since it has a significant influence on the performance of the engine oil. Figure 4 shows the flash point, and viscosity of engine oil has a linear connection with the concentration of nanoparticles. Figure 5 indicates the flash point and thermal conductivity of 0.1 wt. % concentrations increased by 5% and 3%, respectively. The value of pour point had reduced by about 7.4% in other concentrations but had a 3.7% improvement at 0.2 wt. % concentration as compared with the base fluid. According to the following findings, the finest sample of CuO/oil is observed with 0.2 wt. % concentrations of nanolubricant. This sample indicates small changes of viscosity, while improvement is observed with flash point and pour point, as shown in Figure 6.

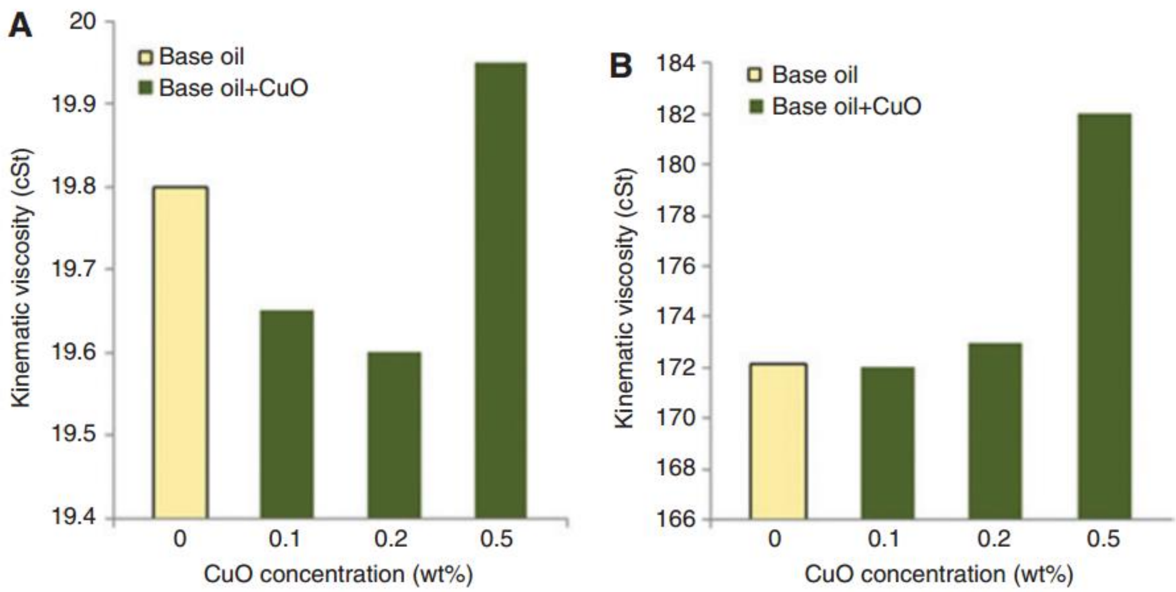

Fig. 4. Influence on kinematic viscosity of lubricants at (A) 100 °C and at (B) 40 °C due to concentration of CuO. Under experimental conditions: grain sizes of CuO were smaller than 100 nm, SAE 20W50 engine oil. Source: [50]

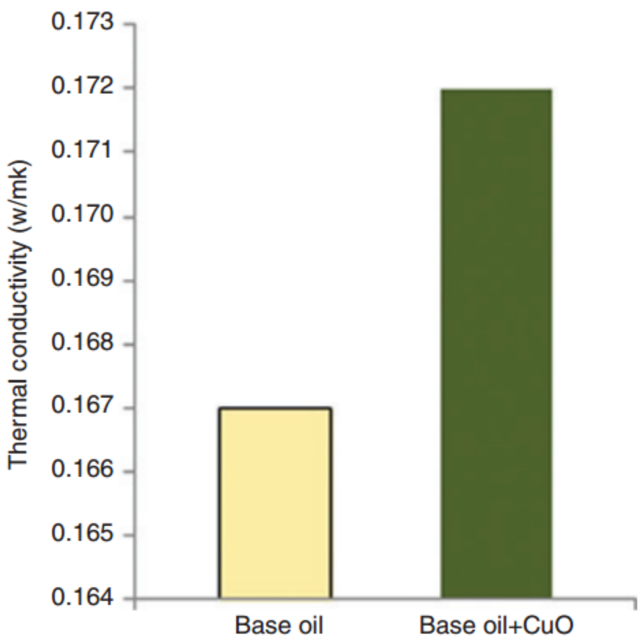

Fig. 5. Influence on thermal conductivity due to the effect 0.1 wt.% concentration of CuO nanoparticles and grain sizes of CuO were smaller than 100 nm. Source: [50]

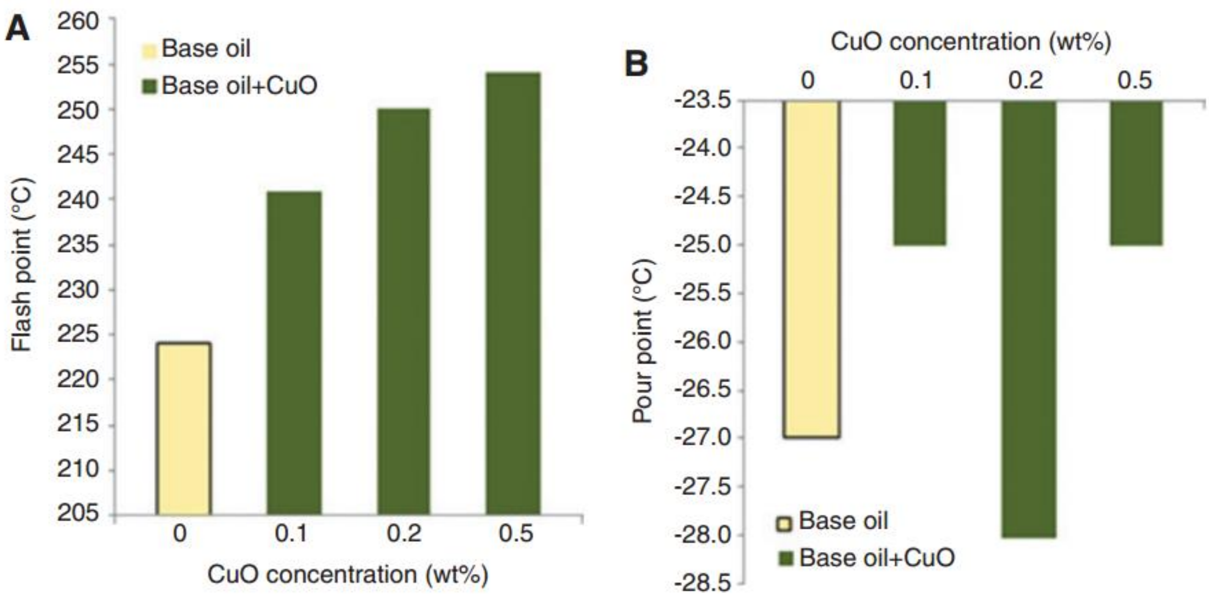

Fig. 6. Influence on flash point (A) and pour point (B) due to CuO concentration. Source: [50]

Simulation of nanoparticles friction properties has been performed by Hu *et al.,* [51] The researchers also examined the influence of copper (Cu) nanoparticles on the solid contact between the friction surfaces by implemented a molecular dynamics technique to expose the mechanisms responsible for the favourable friction properties of nanoparticles. Two models were made, namely, model A (without Cu) and model B (with Cu). The prediction findings revealed that the enhancement in friction properties due to Cu nanoparticles was more significant at low speed than at high speed due to the Cu nanoparticle developing a nano-film on the friction surfaces, as shown in Figure 7. Padgurskas *et al.,* [19] studied the influenced of SAE10 mineral oil dispersed with CuO, Cu, and Fe nanoparticles. A tribological investigation indicated that up to 1.5 times are decreasing in the wear and friction coefficient of friction pairs. Tribological findings show that almost 47% decrease in wear was observed when using the copper nanoparticles.

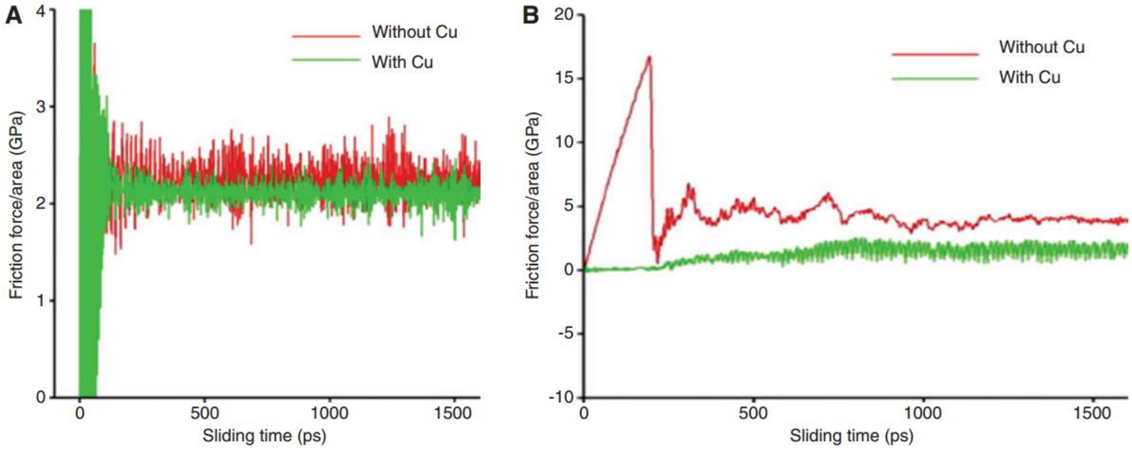

Fig. 7. Influence of Cu nanoparticles on friction force/area with respect to sliding time at (A) high speed and (B) low speed by molecular dynamics mechanism. Source: [51]

Tribological behaviour effect of CuO and ZnO nanoparticles dispersed in synthetic oil and mineral oil has been studied by Alves *et al.,* [52]. The CuO and ZnO nanoparticles have an average grain size of around 4.35 and 11.71 nm, respectively. An ultrasonic probe is used for about 30 min to mixed 0.5 wt.% concentration of individual ZnO and CuO nanoparticles dispersed in the lubricant. The tribological properties findings show significant enhancement, the dispersion of CuO in synthetic oil slightly improved its tribological properties, but greater performance in decreasing wear and friction was observed with the combination of mineral oil and ZnO owing to good film formation. As compare to ZDDP as oil additive, Cu nanoparticles have superior anti-wear and friction-reduction properties, especially at high loads application. Furthermore, the base oil also enhanced its load-carrying capacity [53]. The presence of nanoparticles for concentrations lower than 0.34% lead promoted to decrease in friction. This is due to the adjustment of contact configuration to more on rolling rather than from the initial sliding mechanism. As soon as the concentration was further increased, the contact configuration returned back to more on a sliding mechanism; therefore, the friction coefficient becomes increased. Dispersion of oil with nanoparticle additives also lead to slightly increased viscosity [3].

Choi *et al.,* [54] inspected the influence of nanoparticles in the oil as a friction reducer. The copper nanoparticles have the average sizes of 25 nm and 60 nm, respectively. The copper nanoparticles added in oil for 0.1 vol.% concentration. The findings exposed that under a load of 3000 N, the average friction coefficient for nanolubricants reduces by 39% and 44% with 60 nm and 25 nm copper nanoparticles, respectively. The copper nanolubricant produces tribo-film, which separates two friction surfaces prevents direct contacts between them. Furthermore, the decrease of friction is contributed by the low hardness of the tribo-film, while the rises in the elastic deformation of the contact surface and reduces wear especially at the higher temperature of the oil is owing to its low elastic modulus. Lastly, the presence of the soft film on the worn surface may increase the contact area and offer fast relaxation and decrease contact stress [25]. Huang *et al.,* [55] performed an investigation using a four-ball machine to explore the influence on tribological properties of engine oil with combined additives. The finest interaction influence was observed under the combination of 0.25 wt.% nano-silica with 0.3 wt.%; nano-Cu. A lowest wear scar diameter and friction coefficient were found with optimum nanolubricant of N32 oil enriched with 0.5% concentrations of Cu nanoparticles. The nanoparticles might lead in rolling effect between the rubbing surfaces, and the friction condition is transformed from sliding to rolling. Thus, the decreasing coefficient of friction has been observed [56].

Wu *et al.,* [20] investigate the tribological properties of diamond, TiO_2, and CuO nanoparticles as additives dispersed in two standard oils, namely, a base oil (SAE30 LB51163-11) and API-SF engine oil (SAE30 LB51153). All the tested nanoparticles used are sphere-like shape with average grain sizes around 10, 80, and 5 nm for the diamond, TiO_2, and CuO nanoparticles, respectively. The TiO_2 and CuO nanoparticles were used with glycol as the solvent. Both nanolubricants consist of 10% additive solution (0.1% nanoparticles and 9.9% glycol) and 90% standard oil. The observation findings indicate that the coefficients of friction were decreased by 5.8% and 18.4% for the CuO nanoparticles enriched in and the base oil and the SF oil than that of oil without nanoparticles. Peña-Parás *et al.,* [57] also studied the influence of tribological properties at different concentrations of CuO. The findings exposed that at a concentration of 0.01 wt. %, 86% decreased in wear scar diameter had been recorded.

3.2 Application of Cellulose Nanocrystal (CNC) in Nanofluid

Over a century ago, cellulose was used as an energy source, for building materials and clothing in the form of wood and plant fibers. However, these fibers can undergo further mechanical and chemical treatments to produce a more efficient class ofnanocellulose materials. Nanocellulose can be divided into three main subcategories; cellulose nanocrystals, nanofibrillated cellulose, and bacterial nanocellulose. In this study, the focus will be on the cellulose nanocrystal. Numerous research results have shown that nanofluids have outstanding thermophysical properties and are an interesting candidate for applications of heat transfer. Such nanofluids usually contain metal oxide particles likes TiO_2 and SiO_2, but these metal oxides can lead to significant pollution issues. Therefore, a study focuses on introducing the potential of using a plant-based material such as CNC to develop an enhanced and environmentally friendly material for heat transfer applications. Ramachandran measured the thermal conductivity and viscosity of nanocellulose with the weight concentration of 40/60% (EG-water) volume ratio [58]. Experiments were conducted in the temperature range from 30 °C to 70 °C and in the volume, concentration range from 0.1% to 1.3%. Results indicated that the thermal conductivity increases with the increase of mixture temperature and volume of the nanofluid. The enhancement ratio was 1.104 times at 1.3%. Meanwhile, they also found that the viscosity decreases exponentially with temperature and increases as the volume fraction increases. The enhancement ratio was 4.16 times at 1.3%. The author also proposed a new correlation to predict the thermal properties of CNC.

The same author [59] carried out combined experimental-statistical approach for effective thermal conductivity and relative viscosity determination in (EG-water) mixture. CNC were prepared by two different ways, firstly, nanoparticles dispersed in ethylene glycol and water in the ratio of 40: 60, and secondly nanoparticles dispersed in ethylene glycol and water in the ratio of 50:50 by weight. The maximum effective thermal conductivity was 1.127 which is recorded at volume concentration 0.9%, temperature of 70 °C and base ratio of 0.5. Observations showed that effective thermal conductivity depends on the particle volumetric concentration and the temperature. The maximum relative viscosity recorded was 4.521 at volume concentration of 0.9%, 70 °C and base ratio 0.5. Relative viscosity had proportional relation with volume z the density and specific heat capacity for CNC nanoparticles suspended in 40: 60 (by weight) EG and water mixture [58]. Experiments were performed using nanofluids with particle volume percentage from 0.1% to 0.9% and temperatures 30°C to 90 °C. The value of density was found to be highest at a temperature of 30°C and volume concentration of 0.9%. Their result also recorded maximum specific heat capacity is 3972J/kg.°C at a temperature of 90°C and volume concentration of 0.1%. The author also proposed empirical model for relative specific density and relative specific heat capacity.

Meanwhile, a number of studies on CNC in heat transfer application were carried out by some researchers. [60] investigated the thermophysical properties of cellulose nanocrystal (CNC)–ethylene glycol (EG) + Water (W) based nanofluid and the capable to improve the thermal transport and machining performance. Their results prove that the nanofluid capable of reducing the heat generated by the cutting tool which leads for improved tool life. Also, CNC based nanofluid evidently proved to be superior heat transfer fluid compared to MWF to be used in machining operation in conjunction with MQL technique. In another study, [61] conducted a research to evaluated ethylene glycol/nanocellulose-based nanofluid in terms of its thermo-physical properties and its effectiveness in machining performances which is temperature distribution in cutting tool and compare its effectiveness with MWF. They found out that ethylene glycol/nanocellulose-based nanofluid coolant better than the conventional machining coolant which is MWF in MQL cooling system due to a lower percentage of Aluminum of 7.14 wt% cutting tool and more carbon 45.06 wt% with less continuous chips formed.

[62] proposed a Cellulose Nanocrystals (CNC) as green additives for improving tribological properties of lubricants in engine oil. It emerged nano lubricant of CNC particles at 0.1 wt% concentration was the most suitable concentration for improving properties of SAE 40 engine oil. In addition, best results were obtained for nano lubricants with 0.1 wt% of CNC nanoparticles for the reduction of COF. Meanwhile, for the wear rate value, the reduction was observed maximum, up to 69% when the concentration of 0.1% CNC. Also, it shows that the addition of CNC nanoparticles exhibited improved wear behavior compared to the base oil SAE 40. [63,64] numerically and experimentally investigated convection heat transfer coefficients of CNC and Al_2O_3/CNC nanofluilds for different base mixture at concentration of 0.1%, 0.5%, and 0.9% and working temperature of 30, 50 ,70°C in 40:60 (EG:W) base mixture fluid with volume concentration of 0.1%, 0.5%, 0.9% and 1.3% in radiator coolant. Their result revealed addition of CNC provides a better heat transfer efficiency compared to usage of distilled water as radiator coolant. [65] studied the performance characteristics and effectiveness of the radiator with addition of nanoparticles (CNC). It was found that 0.5% of volume concentration nanofluid of ratio 60:40 (EG:W) displays a better rate of heat transfer compared to distilled water. Also, thermal conductivity test showed cellulose nanofluids have better thermal conductivity compared to Ethylene Glycol and the highest thermal conductivity possessed by 0.5% cellulose nanofluids was 0.519 W/m.°C.

4. Optimization of Nanofluid using Response Surface Methodology

Evolution of productions in the area of development and optimization of systems relying on heat transfer causes growing need of designing and introducing optimum lubricant and coolant fluids with high efficiency. Hence, researchers have done abundant endeavors in their empirical, numerical studies and analytical in order to introduce optimized working fluids used in heat transfer systems [66-69]. One of the factors of energy damping in various industries is friction between moving elements, that lubricants are used in order to decrease this friction. Today, because of the impact of lubricants in industries, studies on their properties in order to increase efficiency and decrease costs are highly inevitable.

Response surface methodology (RSM) is the most preferred statistical tool to optimize the significant parameters of any real-time manufacturing process, as it requires a minimum set of experiments and provide optimum condition settings for maximum yield [70]. As RSM formulates a mathematical matrix and considers multiple variables and their interactions it required a lower number of experimental trails as compared to ANN [71]. Therefore, using RSM various studies successfully validated the experimental results without any assumptions. In one of such studies, Nasirzadehroshenin *et al.,* [72] synthesized Al_2O_3-TiO_2 (10%) nano composite in three sizes and dispersed them in water to synthesize hybrid nanofluid with 0–0.5% volume fraction at 20–50 ◦C and successfully predicted thermal conductivity and viscosity using RSM and ANN. Analysis of variance (ANOVA) table confirmed that, temperature (A), concentration (B), particle size(C) and interaction term (AB) showed significant impact on the model with lower P-value. Peng *et al.,* [73] predicted and optimized the thermal conductivity of CuO/water nanofluid using RSM at φ = 0.1–0.4 vol% and 25–40 ◦C. Authors claimed that for CuO/water nanofluid the proposed model can extrapolate and interpolate the data with less than 2% accuracy. Salehnezha *et al.,* [45] studied the rheological properties of starch-ZnO/water nanofluid in the application of water based drilling fluid using RSM. Here, the effect of ultrasonication time, Starch and ZnO nanoparticles percentage on thermal conductivity, flow behaviour, yield point and plastic point were analysed, and their concerning correlations were proposed.

Optimization of thermal systems has inspired researchers because an optimized energy system results in reduced operating cost, reduction in harmful effects on the environment, and sparing in fossil energy sources. [74] applied multi-objective optimization techniques for modeling and optimizing properties of nanofluids. The optimization of viscosity for MWCNTs-ZnO (10–90%)/5W50 nanolubricant was performed by [75]. They used shear rates, temperature, and volume fraction as input variables for optimizing viscosity. The minimum and maximum modes of viscosity were obtained with respect to the input variables. [76] optimized the operating parameters for an automotive air conditioning system with SiO_2/PAG nanolubricant as a refrigerant. The design of experiment was carried out by using RSM which significantly reduced the computational time by reducing the number of experiments. It was concluded that the desirability method of RSM was the easiest and efficient optimization strategy for the work. [77] modeled and optimized thermophysical properties of graphene nanolubricants using RSM. Optimization was performed for each case of individual and multiple responses and it was evident that all the cases inspected favor the content of pure groundnut oil. [78] recasted and optimized the viscosity of ZnO/SAE 50 nanolubricant by using response surface methodology and sensitivity analysis. A novel regression model was used to predict the experimental value of viscosity with R^2 and adj-R^2 being 0.9966 and 0.9965, respectively, showing better estimation with a standard deviation of 3%.

5. Summary and Research Gap

As concluding remark, this section described the significance of recent developments in lubrication science and nanotechnology shows the addition of nanoparticles to engine oils can fill scars and grooves of the friction zone. At the same time, nanoparticles chemically react with engine oil to form a tribo-film above the nanoparticles when the contact pressure and temperature are enough to cause a reaction between the nanoparticles in the lubricating oil and friction surfaces. The deposition of nanoparticles makes the worn surface flat and smooth, which can result in an improvement in the tribological characteristics of internal combustion engines. The results show that the tribological characteristics are affected by composition, shape, concentration, grain size, and dispersion stabilization of nanoparticles in base engine oils. Although the current study investigated ways of improving the tribological behaviour of internal combustion engines via the addition of nanoparticles to engine oils, the use of nanoparticles poses a serious technical challenge of a capping layer structure and the nature of its interaction with friction surfaces under high temperatures, to match with quality standards established. This study involving the structure of tribo-film and the nature of its interaction is important and might assist in bridging the gap between conventional macrotribology and advanced nanotribology. This would significantly lower the cost of the process and will make it commercially more viable than at present. There is still plenty of work for further development.

This chapter also summarizes the effect of nanoparticle additives on tribological properties of base lubricants. Coefficient of friction and anti-wear properties of nanolubricant is significantly enhanced as compared to base lubricant due to various mechanisms such as ball bearing, mending, tribofilm formation and surface polishing effects. Metal and metal oxide nanoparticles are most widely used as additives to produce an enhancement in the properties of lubricants. Thus, the prospect of using nanolubricants as an alternative to conventional lubricants appears to be very promising. According to the literature review, it is observed that the experimental work on a piston ring and cylinder liner contact is important to investigate the influence of nanolubricants, especially the CNC-CuO nanoparticles on the of thermophysical properties and tribological behaviour. Furthermore, there are limited studies conducted to investigate the effect nanolubricant, especially from the CNC-CuO nanoparticles on the piston ring and cylinder liner contact. Therefore, due to the huge gap available, nanolubricant from CNC-CuO nanoparticles had been used in this study to investigate its potential as nanolubricant especially in the aspect of the tribological behaviour of CNC-CuO nanolubricants for piston ring and cylinder liner contact, and predict the suitable regression correlation using regression method and optimize the thermophysical properties and tribological factor of nanolubricant using RSM method. Table 3 below shows the research gap and summary finding.

Table 3
Research gap and summary finding

References	Topic of study	Key Findings (Gaps)
[79,80]	Tribological performance	• Limited researches on the effect of hybrid CNC-CuO nanoparticles on tribological performance and using sliding wear test
[81,82]	Optimization of operating parameters for tribological performance	• Limited study which employing BBD and RSM to optimize tribological performance. • None of research has yet published for thermophysical and tribological performance optimization for the use of CNC-CuO nanoparticle in engine oil

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