



Thermophysical and Tribological Analysis of Non-edible Coconut Oil with CuO Nanoparticles

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Received: 16.02.2026 Accepted: 21.03.2026 Published: 30.06.2026

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ABSTRACT

The study investigates the thermophysical and tribological behavior of non-edible coconut oil when used as a base fluid with copper oxide (CuO) nanoparticles. The measured thermophysical properties include kinematic and dynamic viscosities, acid value, flash point, fire point, and transesterification characteristics. Tribological performance was evaluated using a pin-on-disc tribometer (ASTM G99) to determine the coefficient of friction and wear rate. Results show that the addition of CuO nanoparticles increases viscosity and improves load-carrying capacity. The underlying mechanisms are discussed, and guidance on the optimal concentrations of vegetable oil-based nano-lubricants is provided. The results indicate that the optimal concentration of CuO nanoparticle-based nano-lubricant is around 0.38 wt.%, at which the coefficient of friction and wear rate are minimized. The addition of nanoparticles can improve the overall lubricating properties of the oil, making it suitable for lubrication applications. The addition of CuO nanoparticles to the base oil increases the viscosity by 30–32%, while the decrease in viscosity at elevated temperatures becomes less pronounced with increasing nanoparticle concentration. The average wear rate is reduced by approximately 65–70% compared with that of the base oil alone. At the optimum CuO nanoparticle concentration of 0.38 wt.%, the wear rate is reduced by 72% compared with that of the base oil.

Keywords: Non-edible coconut oil; CuO nanoparticles; Nano-lubrication; Tribology; Fluid friction; Wear rate.

1. INTRODUCTION

Vegetable oils are biodegradable and renewable in nature. These oils are used as base lubricants due to their high lubricity and environmental friendliness. Non-edible coconut oil with high saturated fatty acid content and oxidative stability is being studied as a lubricant. Pure vegetable oils lack sufficient extreme-pressure and anti-wear performance for heavy-load tribological applications. Nanoparticle additives such as CuO have been reported to improve lubrication and wear resistance. Recent studies have shown that the blending of nanoparticles into base oils enhances lubrication performance by improving load-carrying capacity, thermal stability, and anti-wear properties. Nanoparticles such as CuO, TiO₂, Al₂O₃, and WS₂ have been widely investigated due to their ability to form protective tribofilms and reduce friction between sliding surfaces (Khan *et al.* 2019; Rashin and Hemalatha, 2013; Kumar and Kumar, 2023). These nano-lubricants have demonstrated considerable improvements in viscosity stability and wear resistance under boundary lubrication conditions. Even though several studies have investigated vegetable oil-based nano-lubricants, limited research has been conducted on non-edible coconut oil combined with CuO nanoparticles for tribological applications. In particular, the influence of nanoparticle concentration on viscosity variation, wear behavior, and optimal lubrication performance is not explored sufficiently.

The present work aims to experimentally evaluate the thermophysical and tribological characteristics of non-edible coconut oil enhanced with CuO nanoparticles and determine the optimal nanoparticle concentration for improved lubrication performance.

2. REVIEW OF LITERATURE

The exploration of coconut oil as a base fluid for nano-lubricants has gained importance due to its biodegradability, oxidative stability, and high saturated fatty acid content (Khan *et al.* 2019). Different experimental studies show that dispersing metallic nanoparticles such as copper and silver into coconut oil in a certain percentage significantly enhances its tribological performance by reducing wear and friction in metal cutting applications (Yang, 2014). Similarly, the addition of CuO nanoparticles into vegetable oils has demonstrated improvements in viscosity stability, load-carrying capacity, and wear resistance (Jhodkar and Gupta, 2020). Tungsten disulfide (WS₂) nanoparticles have been experimentally studied for their ability to form low-shear tribofilms, which effectively reduce friction and wear under boundary lubrication conditions (Greenberg *et al.* 2004). Hybrid nanofluids that combine metallic oxides with lamellar solids have shown synergistic effects, which offer superior thermal conductivity and tribological behaviour compared to single-component systems

Several studies have evaluated the rheological and tribological behavior of coconut oil modified with various nanoparticles, and confirmed its suitability for industrial lubrication under high-pressure and high-temperature conditions (Jhodkar and Gupta, 2020; Cortes and Ortega, 2019; Rashin and Hemalatha, 2013). Research on CuO–coconut oil nanofluids has revealed enhanced viscosity and thermal stability, particularly when optimized for nanoparticle concentration and dispersion techniques (Gao *et al.* 2025; Aldana *et al.* 2016). WS₂-based lubricant shows promise in extreme pressure regimes, with applications extending to automotive and aerospace sectors (Kumar and Kumar, 2023). Hybrid formulations combining CuO and WS₂ have demonstrated reduced wear, improved heat dissipation, and better load-bearing capacity, especially when synthesized using ultrasonic dispersion and surfactant-assisted stabilization methods (Abd Elhaseeb *et al.* 2023; Gupta *et al.* 2021).

Moreover, studies on different vegetable oils have highlighted coconut oil's superior oxidative stability and biodegradability (Rosli, 2019). Investigations into nanoparticle morphology and surface characteristics have shown that spherical and lamellar structures contribute to lubrication mechanisms, influencing both frictional and thermal behaviour (Garcia *et al.* 2024). Finally, advancements in nanofluid synthesis and characterization techniques have enabled more reliable formulations, providing a way for its industrial adoption (Uniyal *et al.* 2024). The effect of nano-lubricant produced from non-edible coconut oil and its analysis are seldom carried out. To address this gap, in this work, the effect of copper oxide nanoparticles in non-edible coconut oil from a tribological perspective has been studied. Previous investigations have reported that metal oxide nanoparticles significantly improve the tribological behavior of vegetable oil-based lubricants. CuO nanoparticles reduce friction and wear due to their ability to form protective tribofilms on contact surfaces. Similarly, studies involving WS₂ nanoparticles demonstrated improved load-bearing capacity and reduced surface damage during sliding contact. While several nano-lubricant studies have been conducted using edible vegetable oils such as soybean and palm oil, the tribological performance of non-edible coconut oil with CuO nanoparticle additives remains insufficiently investigated. Understanding the combined effect of nanoparticle concentration and temperature-dependent viscosity behavior is therefore essential for developing environmentally sustainable lubrication systems (Khan *et al.* 2019; Gupta *et al.* 2021; Rosli, 2019).

3. MATERIALS AND METHODS

The dried kernel of the coconut is known as copra. Non-edible coconut oil is obtained from the coconut kernel containing the testa, the outer brownish layer surrounding the white endosperm. As a result, it

contains higher levels of free fatty acids than edible coconut oil produced from the white coconut kernel. Non-edible coconut oil has been selected as the base fluid in this analysis. The CuO nanoparticles used in this study possessed a purity greater than 99%, obtained from Sisco Research Laboratories, Kerala, India. The size of the nanoparticles was determined from scanning electron microscopy (SEM) images and was found to range from 100 to 150 nm. The size of the nanoparticles was verified using scanning electron microscopy (SEM) images and was found to range from 100 to 150 nm. The addition of CuO nanoparticles to the oil significantly enhances its thermophysical and tribological properties. The surfactant selected in this experimental work is Polysorbate 20 (Tween 20). It is widely used as a surfactant, emulsifier, and stabilizer in cosmetic, food, and pharmaceutical applications. For the tribological analysis, a pin-on-disc tribometer was used in accordance with ASTM G99 standards. Thermophysical analysis included viscosity measurements, flash point and fire point determination, acid value determination by titration against a standard KOH solution, and oil transesterification. Each experiment was conducted in triplicate under identical operating conditions, and the average values were reported to ensure the reliability of the results.

3.1 Sample Preparation

For pin-on-disc tribometer analysis, the lubricant samples were prepared using the base oil alone and then with nanoparticle additions at weight percentages of 0.1, 0.2, 0.3, and 0.4. The required nanoparticles were accurately measured using a digital weighing balance with a butter paper placed on the pan to avoid material loss. The measured nanoparticles were directly added to the base oil and dispersed using a magnetic stirrer for 1 h. The stirring process was intermittently paused for 2 min every 15 min to prevent excessive heating and to promote uniform dispersion. Subsequently, Tween 20 surfactant of 0.2 mL was added to enhance dispersion stability by reducing nanoparticle agglomeration. After further stirring to ensure homogeneity, the prepared samples were subjected to pin-on-disc tribometer testing.

3.2 Thermophysical Measurements

Experimental evaluation of the kinematic and dynamic viscosities of base oil, along with different compositions of nanoparticles, was carried out using the redwood viscometer apparatus. The acid value was obtained by titrating the solution with standard KOH solution. The transesterification process was used to transform natural triglycerides into esters. Flash point and fire point values were obtained by using the Cleveland open cup apparatus in accordance with ASTM D93.

3.3 Tribological Test

Tribological performance of the base oil and nanoparticle-enhanced non-edible coconut oil samples was evaluated using a pin-on-disc tribometer in accordance with ASTM G99. At the time of experimental analysis, the tribometer continuously recorded the coefficient of friction (COF) variation during sliding. The specimen consists of hardened aluminium pins (BS 1490 LM6) sliding against a polished steel disc with an average surface roughness of approximately 0.05 μm . Before testing, both the pin and the disc were cleaned thoroughly with acetone to remove contaminants and dried in ambient conditions.

Experiments were conducted under normal loads of 50 N at a sliding speed of 65 rpm with a total sliding distance ranging between 1000 and 5000 m. All tests were performed at ambient temperature. The parameters recorded include wear in μm and frictional force in N. Each test condition was conducted in triplicate, and the average value was reported.

4. RESULTS AND DISCUSSION

The analysis revealed that non-edible coconut oil exhibits high viscosity and relatively high flash and fire points. The analysis indicated that the addition of nanoparticles improved the thermophysical properties of nano-lubricants. The experimental results indicated that the viscosity of non-edible coconut oil decreases with increasing temperature, which is consistent with the typical behavior of liquid lubricants. However, the addition of CuO nanoparticles significantly enhances viscosity stability. At a CuO concentration of 0.4 wt.%, the viscosity increased by approximately 30% compared with that of the base oil at 50 °C, indicating enhanced load-bearing capability and improved lubricant film formation between the sliding surfaces.

Compared with the dry sliding condition, the application of non-edible coconut oil alone reduced the frictional force and wear. The COF decreased gradually with increasing CuO nanoparticle concentration.

Initial experiments showed that the addition of nanoparticles to non-edible coconut oil resulted in a reduction in friction with increasing nanoparticle

concentration. Beyond an optimum concentration of 0.38 wt.%, the COF increased. The initial reduction in friction may be attributed to the transition from sliding motion to a rolling mechanism facilitated by the nanoparticles. At higher nanoparticle concentrations, the beneficial rolling effect gradually diminished. Consequently, increased solid-to-solid contact occurred, leading to an increase in the COF. The reduction in friction and wear observed in the nano-lubricant can be attributed to several lubrication mechanisms associated with the nanoparticles. The rolling effect of the nanoparticles reduces direct metal-to-metal contact by acting as nanoscale ball bearings between the sliding surfaces. Moreover, the nanoparticles form a protective tribofilm on the contact surfaces, thereby reducing severe surface damage during sliding. Furthermore, the polishing effect of nanoparticles smoothen surface asperities and decreases friction, and improves overall wear resistance.

Tables 1 and 2, and Figs. 1 and 2 show the variation of kinematic and dynamic viscosities with temperature for non-edible coconut oil with different CuO concentrations. At the initial temperature (50 °C), the difference in viscosity among the samples was greater than that observed at the highest measured temperature of 90 °C. Viscosity gradually decreases with increasing temperature; however, the rate of decrease becomes less pronounced as the nanoparticle concentration increases. The increase in oil viscosity is beneficial because it promotes the formation of a load-bearing protective film that prevents direct metal-to-metal contact. By maintaining this durable film, the lubricant significantly reduces wear on mechanical components. Furthermore, higher viscosity is vital for ensuring particle dispersion, as it keeps CuO nanoparticles stable and uniformly suspended within the oil, preventing them from settling over time and maintaining consistent performance.

Table 1. Kinematic viscosity (cm^2/s) at various temperatures

Temperature (°C)	Base oil	0.1% CuO	0.2% CuO	0.3% CuO	0.4% CuO
50	0.224	0.240	0.255	0.270	0.288
60	0.189	0.201	0.213	0.225	0.234
70	0.168	0.177	0.186	0.195	0.213
80	0.132	0.138	0.144	0.150	0.182
90	0.102	0.106	0.110	0.114	0.123

Table 2. Dynamic viscosity (poise) at various temperatures

Temperature (°C)	Density (g/cm^3)	Base oil	0.1% CuO	0.2% CuO	0.3% CuO	0.4% CuO
50	0.907	0.2032	0.2177	0.2313	0.2449	0.2632
60	0.900	0.1701	0.1809	0.1917	0.2025	0.2132
70	0.893	0.1500	0.1581	0.1664	0.1741	0.1782
80	0.886	0.1169	0.1221	0.1276	0.1329	0.1349
90	0.879	0.0896	0.0932	0.0967	0.1002	0.1121

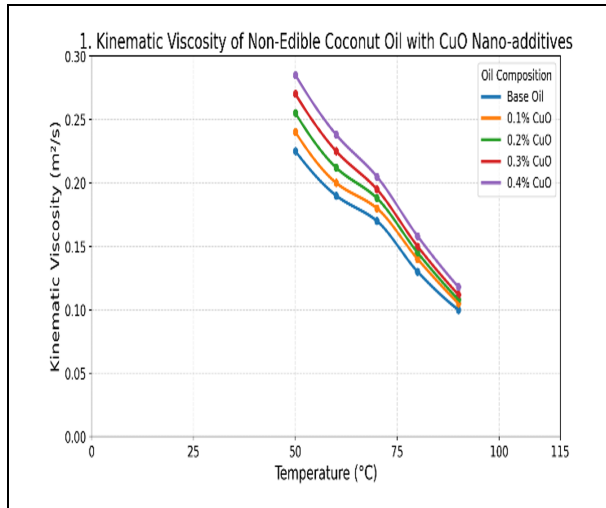


Fig. 1: Variation of kinematic viscosity with temperature for non-edible coconut oil with different CuO nanoparticle concentrations

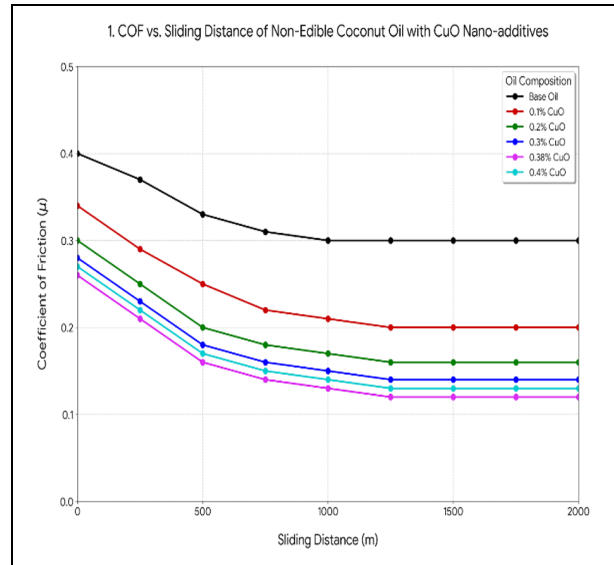


Fig. 3: Variation of COF with sliding distance for different CuO nanoparticle concentrations

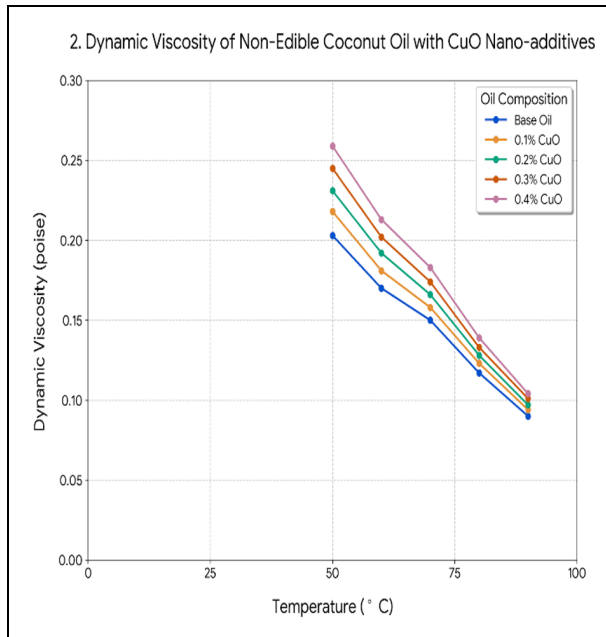


Fig. 2: Variation of dynamic viscosity with temperature for non-edible coconut oil containing CuO nanoparticles

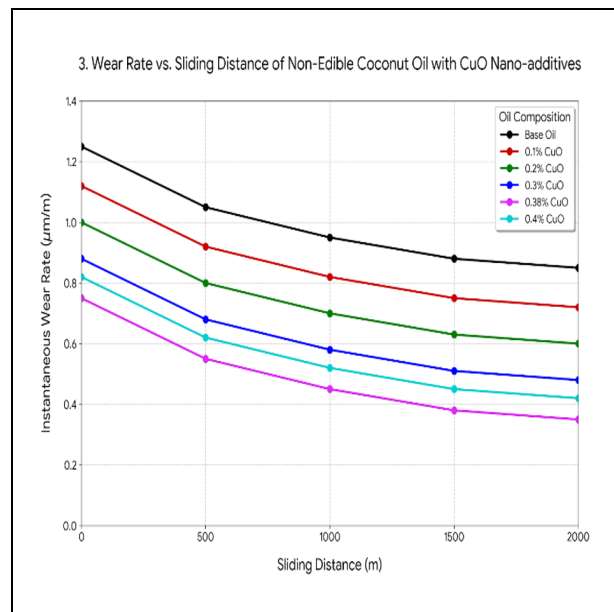


Fig. 4: Variation of wear rate with sliding distance for different concentration of CuO nanoparticle

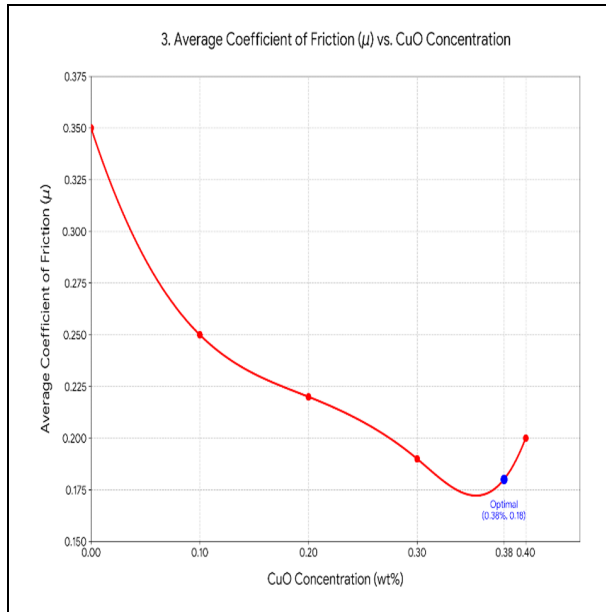


Fig. 5: Variation of average COF with CuO concentration

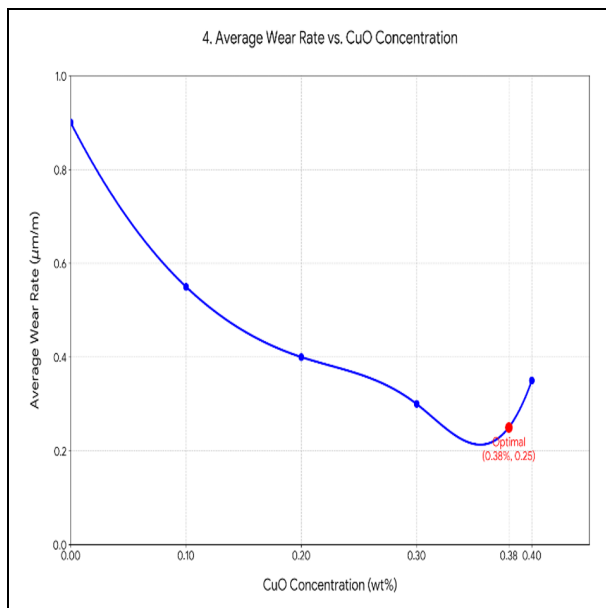


Fig. 6: Variation of average wear rate with CuO concentration

Fig. 3 shows the variation in the COF with sliding distance. Initially, the surface asperities of the pin and disc were prominent, resulting in a higher COF. After a sliding distance of approximately 250 m, the system reaches the run-in stage, and the COF stabilizes at an approximately constant value. Fig. 4 shows the variation in wear rate with sliding distance. A lower COF is associated with a lower wear rate. The lubrication regime observed in this study is predominantly within the boundary lubrication region. According to the Stribeck curve reported by Rosli (2019), the operating conditions correspond to the boundary lubrication regime. Figs. 5 and 6 show the variation in COF and wear rate with

nanoparticle concentration. The addition of 0.38 wt.% nanoparticles to the base oil resulted in the optimum COF and wear rate values.

5. CONCLUSION

- The viscosity of the nano-lubricant remained stable during prolonged storage.
- Initially, the COF was high because of asperity contact between the sliding surfaces; after the run-in period, both the COF and wear rate stabilized.
- The optimum CuO nanoparticle concentration for minimizing the COF and wear rate was 0.38 wt.%.
- The reduction in friction observed with the nano-lubricant is attributed to the transition from sliding friction to a rolling mechanism facilitated by the nanoparticles.
- Beyond the optimum nanoparticle concentration, solid-to-solid contact between the sliding surfaces increases, resulting in a gradual increase in the COF.
- The addition of CuO nanoparticles increased the viscosity by approximately 30–32%.
- The results indicate that CuO-based nano-lubricants have strong potential as environmentally friendly alternatives to conventional lubricants.
- Future research could focus on long-term tribological testing, thermal stability analysis, and the investigation of hybrid nanoparticle systems to further improve lubrication performance.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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