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Comparative Study of the Viscosities and Thermal Conductivities of Groundnut and Coconut Oils Dispersed with Graphene Particles Reinforced with Oleic Acid

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Abstract: *This study addresses some challenges accrued using mineral oil as cutting fluid and suggest alternatives to suitable, eco-friendly, non-toxic and biodegradable solution using vegetable oil. Oils extracted from vegetables are environmentally friendly, biodegradable, and non-toxic compared with mineral oils. To investigate their optimal use for industrial applications, this study tested base oil's thermal-physical properties (kinematic viscosity and thermal conductivity). Temperatures of 40*^{0}*C and 100*^{0}*C were considered for kinematic viscosity, and it was improved with the infusion of graphene nanoparticles and oleic acid. The thermal conductivities of the base oils at temperatures of 50*^{0}*C, 60*^{0}*C, and 70*^{0}*C were tested against the addition of graphene nanoparticles at the same temperatures with compositions of 0.001%, 0.003%, and 0.005%. Thermal conductivity of the groundnut oil at 50, 60 and 70*^{0}*C were 0.495, 0.320 and 0.225 Wm-*^{1}*K-*^{1}*. The average of the compositions at 50, 60 and 70*^{0}*C were 0.527, 0.33 and 0.25 Wm-*^{1}*K-*^{1}*. Compare to coconut oil at 50, 60 and 70*^{0}*C were 0.534, 0.318 and 0.214 Wm-*^{1}*K-*^{1}*, and the average of the compositions at 50, 60 and 70*^{0}*C were 0.622, 0.36 and 0.24 Wm-*^{1}*K-*^{1}*. Kinematic viscosity increments of coconut oil performed better than groundnut oil at 0.001*wt% *with 40*^{0}*C is 7.15% and 3.68% for groundnut oil. Groundnut edged coconut oil at 0.003*wt% *at 40*^{0}*C 17.98% and 11.83%. Similarly, with 0.005*wt% *at 100*^{0}*C coconut oil improve with 63.70% compare 59.73% of groundnut oil. Groundnut oil has a higher viscosity index than coconut oil without the addition of nano-lubricant 436.3 and 209. With the infusion of nano-lubricant the average viscosity index for groundnut oil is 535.17 compare to 406.25 of the coconut oils. It can be verified that the infusion of graphene nanoparticles in both oils can be deployed in machining applications to reduce the friction between contacting surfaces and dissipate heat from the cutting zone.*

Keywords: *Groundnut Oil, Coconut Oil, Graphene Nanoparticles, Oleic Acid, Thermal Conductivity, Kinematic Viscosity.*

1. INTRODUCTION

Within the domain of metal processing, cutting fluids find widespread application in operations such as turning [1], milling [2-3], drilling, and grinding [4-5]. These fluids serve a multifaceted purpose, functioning as coolants, lubricants, cleaning agents, and rust preventatives during the machining process. By reducing cutting temperatures, extending tool lifespan, and enhancing the final surface finish of the metal workpiece, cutting fluids contribute significantly to minimizing tool wear [6]. The base oil component of cutting fluids can be derived from mineral, synthetic, or vegetable sources. Notably, mineral oil-based fluids, extracted from petroleum, constitute roughly 85% of cutting fluids employed globally [7-8]. Mineral oil cutting fluids, derived from petroleum, remain the most prevalent coolant and lubricant employed in machining operations today. However, their widespread use is overshadowed by significant drawbacks. These fluids exhibit high levels of toxicity and resist biodegradation, posing a substantial threat to both environmental health and worker safety [9]. Beyond the well-documented instances of skin irritation and allergies associated with mineral oil exposure, a further concern lies in the generation of microbial toxins. The presence of bacteria and fungi, particularly within water-soluble cutting fluids, fosters the production of these toxins, which can have detrimental health effects on machine operators [10].

To decrease friction, limit wear, transfer heat, get rid of impurities, and boost efficiency, lubrication is necessary between two moving surfaces. [11-12]. Mineral oils are falling short of expectations due to their hostile nature to the environment (toxic and non-biodegradable) and the lasting effects on the human operators (skin irritations) who use it in the manufacturing industries [12-14]. The deleterious effects of conventional cutting fluids on both the environment and human health (particularly machinists) have spurred a significant shift towards environmentally friendly alternatives. Because there is a rise in awareness about protecting the environment and personnel, the need for environmentally friendly lubricants has recently increased. These alternatives encompass eco-friendly and gaseous cutting fluids. Notably, vegetable

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oil-based lubricants offer a compelling solution due to their biodegradability and non-toxic properties, standing in stark contrast to conventional mineral oil-based metalworking fluids [15-16]. Vegetable oils can be extracted from plants using solvent extraction or mechanical pressing. Vegetable oils are becoming increasingly popular as base oil alternatives to mineral oils because they offer several advantages, including a high viscosity index, flash point, low toxicity, low volatility, and high biodegradability. Triacyl glycerides are the primary constituents of vegetable oils [17].

Vegetable oils are classified based on their primary fatty acid contents. These classifications are: Lauric acid, Oleic-linoleic oils, Palm oil, Olive oil, Cottonseed oil, Sunflower oil, Soya bean oil, Erucic acid and Ricin oleic acid [17-21]. Vegetable oils are safe, non-toxic, readily biodegradable products because they are natural. They are therefore potential applications for the basic oils of lubricating oil that are environmentally friendly. Biolubricants have good viscosity, which allow ease of flow into contacting surface in addition to friction reduction. Additional crucial attributes of biolubricating fluids encompass cost-effectiveness, source availability, environmental compatibility, and thermal stability. Furthermore, properties such as toxicity, corrosivity, flammability, chemical stability, and material compatibility are also of significant consideration [22-24]. However, their oxidation and thermal instability under elevated temperature necessitated the need of adding additives to enhance the performance of the vegetable oils [25-26].

This research endeavours to develop a suitable alternative to conventional mineral oil-based cutting fluids. The proposed solution involves formulating a novel cutting fluid utilizing vegetable oils, particularly groundnut and coconut oils. This investigation will focus on identifying the optimal and precise concentration of nanoparticle additives to achieve the desired viscosity characteristics. The formulated cutting fluid would possess appropriate viscosity to function effectively as a coolant and lubricant during machining processes. This research is particularly significant due to the potential for improved environmental and human health outcomes. The biodegradability of vegetable oils and the reduced toxicity compared to mineral oil-based fluids contribute to a more sustainable machining environment for operators and the surrounding ecology. The development of this eco-friendly cutting fluid aligns with broader efforts to address global climate change by promoting more sustainable manufacturing practices. The groundnut and coconut oil plant were chosen as the base oils for the study based on their specified properties as highlighted in the Tables 1 and 2.

Table 1: Properties of groundnut oil [27]

Property	**Value**
Colour at Room Temperature	Light Yellow
Density, Gm^{-3} At Room Temp.	0.919
Kinematic Viscosity, Cst at 40 ^{O}C	28.43
Kinematic Viscosity, Cst at 100 ^{O}C	14.63
Specific Heat, J (Kg ^{O}C)$^{-1}$	2100
Flash Point, ^{O}C	290
Pour Point, ^{O}C	21

Table 2: Properties of Coconut oil [25]

Property	**Value**
Colour at Room Temperature	Light Yellow
Density, Gm^{-3} At Room Temp.	0.924
Kinematic Viscosity, Cst at 40 ^{O}C	28.637
Kinematic Viscosity, Cst at 100 ^{O}C	7.226
Specific Heat, J (Kg ^{O}C)$^{-1}$	2100
Flash Point, ^{O}C	290
Pour Point, ^{O}C	21

Base oils are mixed with nanoparticles to improve their thermo-physical and tribological characteristics. These nanoparticles are made up of a range of materials, consisting of ceramics, polymers, metals, and are typically less than 100 nm in size. Animal fats, vegetable oils, synthetic oils, and mineral oils are all suitable lubricants used with nanoparticles. The performance of the lubricants may also be enhanced using additives and surfactants. Oleic acid is one of the commonly used additives in base oils. Oleic acid occurs naturally and can be found in both vegetable and animal-derived fats and oils. The oil has no smell or colour, notwithstanding the potential for commercial yellowish instances. Oleic acid, a monounsaturated omega-9 fatty acid with a lipid number 18:1 cis-9, is a significant product of enzyme nine desaturase. [28]. Due to its energy-saving and property improvements, this technology has been investigated as a sustainable replacement for conventional lubricating techniques. [29]. The behaviour of nanoparticles when distributed in base oils is

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greatly influenced by their physical features, including composition, size, shape, concentration, and nanostructure. These traits may affect the stability, reactivity, and capacity of the nanoparticles to interact with the oil, which may in turn affect how well they operate in a variety of applications, including lubrication and corrosion protection. [30]. Graphene Nanoparticles are a symmetrical array of carbon atoms in a hexagonal pattern consisting of two atoms per unit cell. [31] because of its unique properties as a two-dimensional (2D) atomic crystal, graphene has an exceptional thermal conductivity of approximately 5000 W/mK [32].

2. MATERIALS AND METHODS

2.1 Method of Producing Nano-Lubricant

The same laboratory equipment was used to determine groundnut and coconut oil's thermal physical properties to ensure the accuracy of the results. Groundnut and coconut oil were combined with graphene nanoparticles and oleic acid to obtain groundnut and coconut oil-based concentrations. The volume of the formulation was measured up to 500 ml.

$$\emptyset = \left(\frac{\frac{Mp}{\rho p}}{\frac{Mp}{\rho p} + \frac{Mbf}{\rho bf}} \right) x100 \tag{1}$$

where Ø, M_p, M_{bf}, P_p, and P_{bf}, represent the quantity concentration in percentage, the mass of the nanoparticles, the base oil mass, the density of the nanoparticles, and the base oil density [25].

A suitable scale of 0.002 interval was used for the formulation to determine the percentage composition of graphene, oleic acid, groundnut oil, and coconut oil. The lubricant sample was mixed with the nanoparticles at 0.001 wt%, 0.003 wt%, and 0.005 wt%. The mixture was first swirled for a few minutes using a magnetic stirrer and then placed in an ultrasonic cell crusher noise-isolating chamber machine (OCT-UCC650Y) for an hour to ensure the nanoparticles were evenly dispersed.

2.2 Thermal Conductivity Measurement

Thermal conductivity is a critical thermophysical property influencing lubricant performance. A lubricant with high thermal conductivity facilitates efficient heat transfer, leading to superior cooling capabilities during tribological interactions. The incorporation of nanoparticles into lubricants presents a promising strategy for enhancing thermal conductivity. However, the effectiveness of these additives depends on various parameters, including their shape, size, concentration, and the operating temperature of the lubricant [19]. The thermal conductivity investigations were evaluated using the temperatures of 50 ^{0}C, 60 ^{0}C, and 70 ^{0}C with graphene composition added at 0.001 wt%, 0.003 wt%, and 0.005 wt%, and a uniform 1g of oleic acid. The time needed to attain the target temperature for the concentration of the dispersed nanoparticles of graphene, groundnut oil, coconut oil, and oleic acid was recorded for each composition. The SELEC DTC204 machine was used to record the readings for each sample (100 ml in volume) in a controlled temperature environment. Each concentration was recorded thrice for each temperature range.

2.3 Kinematic Viscosity

A rotational viscometer (model number NDJ-8S) measured the base oil viscosity and nano-lubricant samples. For each measurement, 250 ml of a nano-lubricant sample was poured into a beaker and subjected to a viscosity test at temperatures ranging from 40 °C to 100 °C at a rate of revolution up to 100 rpm. Many researchers had explored the options of varying the temperature in order to understand the behaviour of nanolubricants [26]. There are no limitations to the options available for the varying of temperature and that of the nanoparticle's concentration, many researchers had used varying degrees of options to test the effects of adding various nanoparticles to the base fluid. The researchers [33] uses nanofluid of 1wt%, 3wt% and 5wt% and tested it against temperatures of 15 – 55 °C. The study by [34] employed the use of 0.3wt%, 0.6wt% and 0.9wt% of nanofluid concentration with temperatures of 50 – 90 °C. In their research [35] employed the use of nanofluid 1.02wt% with temperature range from 25 – 50 °C. The researchers [36] uses 0.1wt%, 2wt% of nanofluid and temperatures of 24 – 50 °C. The study conducted by [37] uses temperature ranges of 20 – 70 °C and nanofluid of 0.1wt% and 1wt% concentration. Therefore, this study temperature range of 40 ^{o}C and 100 ^{o}C to evaluate the thermal physical characteristics of groundnut and coconut oil dispersed with nanoparticles.

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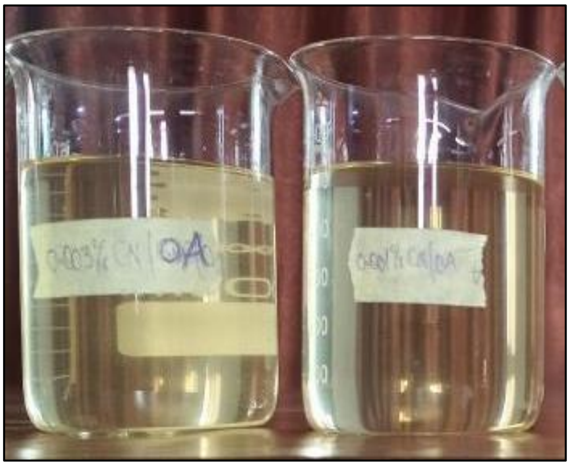

Figure 1: Base oils before adding graphene nanoparticles

Figure 2: Base oils with the addition of graphene nanoparticles and oleic acid

3. RESULTS AND DISCUSSION

Table 3: Viscosities at 40 ^{0}C and 100 ^{0}C and the viscosity index of the groundnut oil with the nano-lubricant samples

Oil Type	**Viscosity at 40^{o}C**	**Viscosity at 100^{0}C**	**Viscosity Index**
Groundnut	28.60	14.70	436.3
0.001% composition	29.71	15.94	489
0.003% composition	30.30	17.50	521.8
0.005% composition	38.60	25.30	594.7

Table 3 shows the result of viscosity of the groundnut oil at the temperatures of 40 and 100 ^{0}C without the addition of nano-lubricant, the base oil viscosity at 40 and 100 ^{0}C were 28.60 and 14.70, showing similarity with the study presented in Table 1 [27]. With the addition of nano-lubricant at composition of 0.001 wt%, 0.003 wt% and 0.005 wt% at the temperatures 40 and 100 ^{0}C. The average of the compositions at 40 ^{0}C is 32.87 and 100 ^{0}C is 19.58 compare to 28.60 and 14.70 of the groundnut oils. The results establish the correlation between the optimum viscosity is determined by the amount of composition and viscosity of the base fluid [25] reported a similar trend in their research.

Table 4: Viscosities at 40 ^{o}C and 100 ^{o}C and the viscosity index of the coconut oil with the nano-lubricant samples.

Oil Type	**Viscosity at 40^{o}C**	**Viscosity at 100^{0}C**	**Viscosity Index**
Coconut	27.97	6.54	209.303
0.001% composition	29.97	8.54	284.7
0.003% composition	31.28	12.48	427.1
0.005% composition	36.46	18.88	506.96

Table 4 shows the result of viscosity of the coconut oil at the temperatures of 40 and 100^{0}C without the addition of nano-lubricant, the base oil viscosity at 40 and 100 ^{0}C were 27.97 and 6.54, showing similarity with the study presented in Table 2 [25]. With the addition of nano-lubricant at composition of 0.001 wt%, 0.003 wt% and 0.005 wt% at the temperatures 40 and 100 ^{0}C. The average of the compositions at 40 ^{0}C is 32.57 and 100 ^{0}C is 13.30 compare to 27.97 and 6.54 of the coconut oils. The results establish the correlation between the optimum viscosity is determined by the amount of

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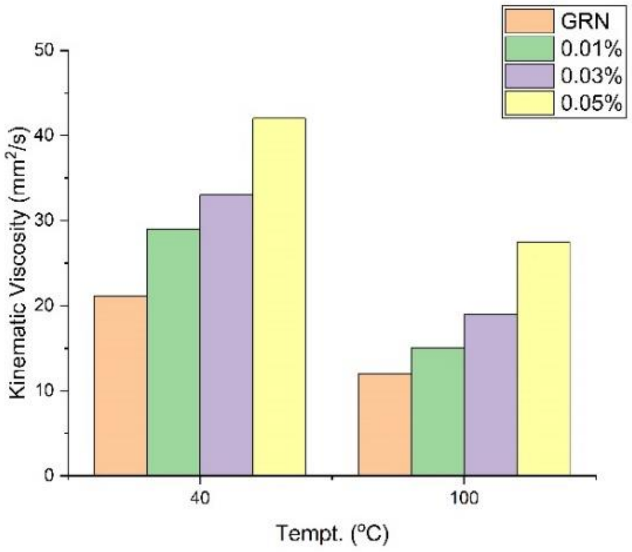
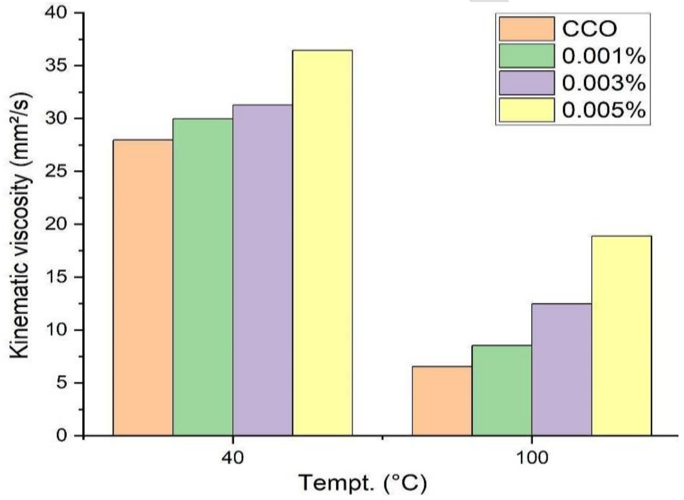
composition and viscosity of the base fluid [25] reported a similar trend in their research, the nano-lubricants were produced with a volume content of 0.1%.



(a) Groundnut oil



(b) Coconut oil

Figure 3(a), (b): Kinematic viscosities at 40 and 100 °C for groundnut oil and coconut oil used as the base oil with the infusion of graphene nanoparticles and oleic acid.

The kinematic viscosity of tested lubricants is represented in figure (a), (b). The nano-enhanced lubricants exhibited an enhanced increase in kinematic viscosity compared to the pure base oils (groundnut and coconut oil) for the varied temperature ranges examined. Incorporating nano-additives into the pure oils augments the viscosity of the nano-enhanced bio-lubricants. As temperature rises, viscosity reduces because the molecular connections between lubricants and the surface of nanoparticles break down with rising temperature. Nevertheless, the viscosity of the nano-enhanced bio-lubricants demonstrates an enhancement compared to the base oil at all measured temperatures. [25], [38-39] documented similar findings in their studies.

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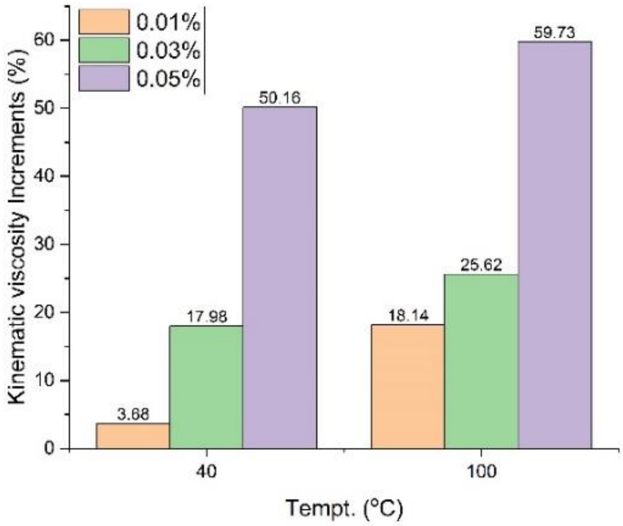
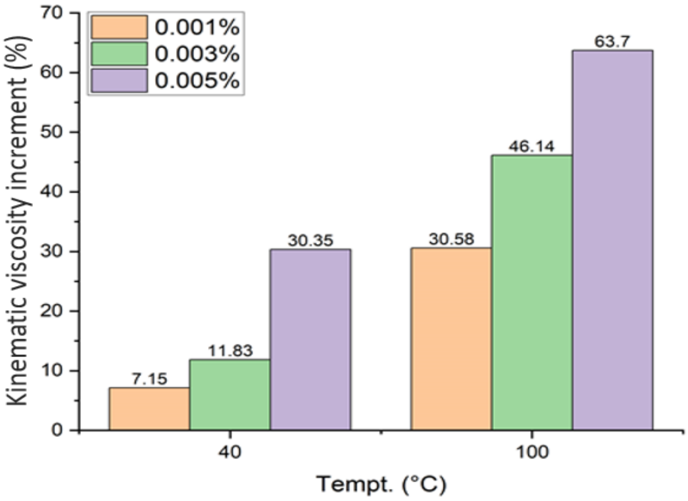


(a) Groundnut oil



(b) Coconut oil

Figure 4(a), (b): Kinematic viscosity increments at 40 ^{o}C and 100 ^{o}C, with the infusion of graphene nanoparticles and oleic acid at ratios of 0.001wt%, 0.003wt%, and 0.005wt% and oleic acid to the base oil.

The figure 4(a) and (b) shows the percentage of kinematic viscosity increment of the addition of nano-lubricant to groundnut and coconut oil, with coconut oil performing better than groundnut oil at 0.001 wt% at 40 ^{o}C 7.15% and 3.68% for groundnut, and groundnut oil having a slight edge over coconut oil at 0.003 wt% 40 ^{o}C 17.98% and 11.83%. Similarly, at 0.005 wt% at 40^{o}C 50.16% of groundnut oil improve best compare to 30.35% coconut oil. While at 0.001wt% of 100 ^{o}C 30.58% for coconut oil and 18.14% for groundnut oil, 0.003 wt% 100 ^{o}C 46.14% and 25.62% for coconut oil and groundnut oil respectively. Similarly, at 0.005 wt% at 100 ^{o}C 63.70% of coconut oil improve best compare to 59.73% groundnut oil. This result showcased that at elevated temperature the coconut oil would be more effective for machining operations than the groundnut oil.

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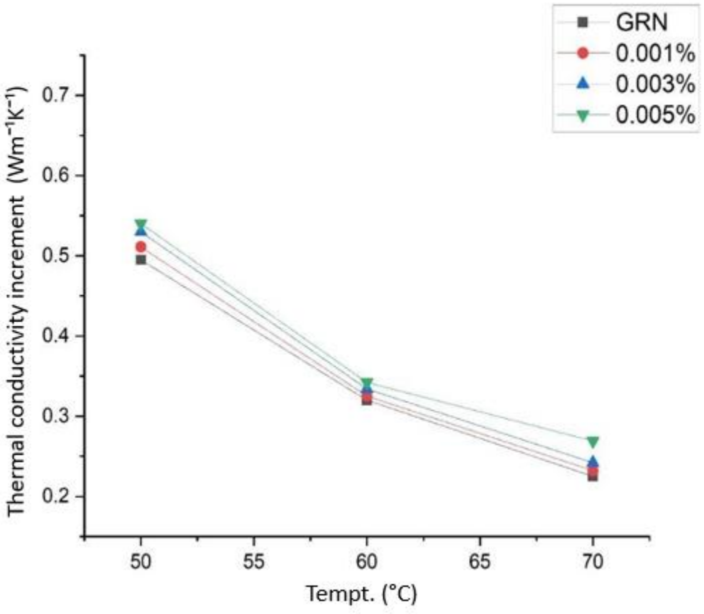
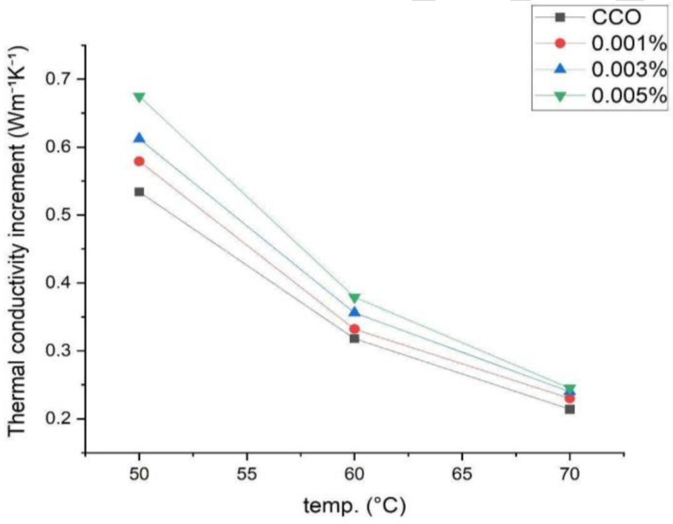


(a) Groundnut oil



(b) Coconut oil

Figure 5(a), (b): Thermal conductivity of the base oil with the infusion of graphene nanoparticles at ratios of 0.001wt%, 0.003wt%, and 0.005wt% and oleic acid to the base oil.

Figure 5(a) show the evaluated analysis of thermal conductivities of the groundnut oils and its improvement with nanoparticles. The groundnut oil at 50, 60 and 70 °C were 0.495, 0.320 and 0.225 Wm^{-1}K^{-1}, while the average of the compositions at 50, 60 and 70 °C were 0.527, 0.33 and 0.25 Wm^{-1}K^{-1}. Hence, the thermal conductivity decreases with increases in temperature and however increases with volume concentration similar to study conducted by [26], [40] using 0.35 – 0.70, 1.05 wt%, and 0.05 – 1 wt% volume concentration of nano addictive. Figure 5(b) show the results of the analysis of thermal conductivities of the coconut oils and its improvement with nanoparticles. The coconut oil at 50, 60 and 70 °C were 0.534, 0.328 and 0.224 Wm^{-1}K^{-1}, while the average of the compositions at 50, 60 and 70 °C were 0.622, 0.36 and 0.24 Wm^{-1}K^{-1}. Hence, the thermal conductivity decreases with increases in temperature and however increases with volume concentration similar to study conducted by [26], [40] using 0.35 – 0.70 and 1.05 wt%, 0.05 - 1wt% volume concentration of nano addictive.

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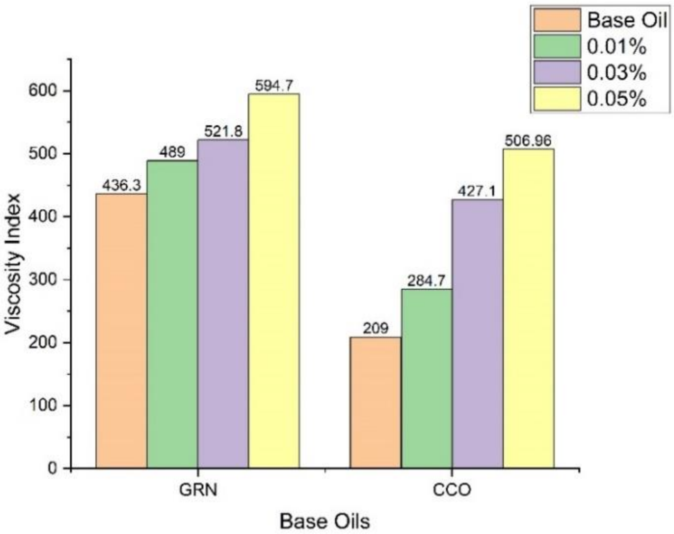

Figure 6: viscosity index of the base oils (groundnut oil and coconut oil) at temperatures of 40 ^{o}C and 100 ^{o}C with the infusion of graphene nanoparticles and oleic acid at a ratio of 0.001 wt%, 0.003 wt%, and 0.005 wt% using ASTM D2270 and ISO 2909.

The viscosity index of the base oils shows that groundnut oil has a higher index than coconut oil without the addition of nano-lubricant 436.3 and 209. With the infusion of nano-lubricant the average viscosity index for groundnut oil is 535.17 compare to 406.25 of the coconut oils. Hence, the groundnut oil has a higher viscosity index compare to coconut oil. A lubricant with a higher viscosity index is preferable for optimal performance, as it promotes the production of a tribo-film, which improves boundary lubrication efficiency across a wide temperature range [25], [41].

4. CONCLUSION

A comparative study on the performance of vegetable oils enhanced with nanoparticles have been conducted. The influence of the addition of nanoparticles on the performance of coconut oil and groundnut oil in terms of viscosity and thermal conductivity were evaluated under same condition of temperature and particle concentration. It's observed that both viscosity and thermal conductivity increases with increase of concentration and decreases with increasing temperature. This finding agrees with earlier study conducted by [26]. However, there is an improvement in performance of viscosity and thermal conductivity of the nanoparticle enhanced biolubricants over the base groundnut and coconut oils. Highlights of the study conducted are summarized as follows:

i. The addition of graphene nanoparticles in the base groundnut and coconut oils improved their thermophysical properties for all the range of concentrations and temperatures considered in this study.
ii. The viscosity of nano-enhanced coconut and groundnut oils in comparison with base oil for all concentrations and temperature indicated superlative performance. At 40 ^{o}C and 100 ^{o}C, the viscosity of groundnut oil enhanced with additives indicated 3.68% and 18.14% for 0.01% concentration respectively. while the viscosity of coconut oil at the same condition of temperature and concentration were 7.15% and 30.58% respectively.
iii. The thermal conductivity at 50 ^{o}C for both nano-enhanced coconut oil and groundnut oils are 0.622 Wm^{-1}K^{-1} and 0.527 Wm^{-1}K^{-1} respectively indicating that coconut oil enhanced with nanoparticles perform better than the base groundnut oil.
iv. Both base oils had shown superior performance and can be adopted as suitable alternative lubricants for machining operations. However, the coconut oil enhanced with graphene nanoparticles indicated superior performance over the groundnut oil enhanced with graphene nanoparticles.

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