Journal of Thermal Engineering
https://jten.yildiz.edu.tr/
https://doi.org/10.47481/jten.0059

RESEARCH ARTICLE

Analyzing neopentyl glycol ester blends for improvement of engine oil tribological properties

Aakula Swathi[1,*], Kodanda Ramarao Chebattina[2], Srinivas Vadapalli[3], Vandana Vemulapalli[4], Uma Chaithanya Pathem[5], Gandhi Pullagura[6], Vasupalli Manoj[7]

[1]Department of Mechanical Engineering, GITAM (Deemed to be University), Visakhapatnam, , 530045 India
[2]Department of Mechanical Engineering, GITAM (Deemed to be University), Visakhapatnam, 530045, India
[3]Professor, school of Marine Engineering and Technology, Indian Maritime University, Kolkata 700088 , India
[4]Assistant Professor, Department of Chemistry, GITAM (Deemed to be University), Visakhapatnam, 530045, India
[5]Associate Professor, Department of Mechanical Engineering, BABA Institute of Technology and Sciences, Visakhapatnam, 530048, India
[6] Department of Mechanical Engineering, GITAM (Deemed to be University), Visakhapatnam, 530045, India
[7] Department of Electrical and Electronics Engineering, GMR Institute of Technology, Vizianagaram, 532127, India

Abstract

The goal of the study was to evaluate the effect of blending Neopentyl Glycol (NPG) Esters (from Calophyllum Inophyllum Oil (Tamanu Oil) with Pebax(R) commercial engine oils. NPG Esters are easily renewable, carbon-neutral, and environmentally friendly alternatives to petroleum-based lubricants and were particularly sought after for their superior performance as lubricants. Engine oils were mixed with NPG Esters in various concentrations (5% to 30% v/v), and then carefully evaluated for their tribological properties. Comparison of the tribological properties of the engine oils changed with NPG Esters showed that the added bio-lubricants would enhance the tribological performance of the base oils by at least 25% over typical base oil viscosity recommendations. However, the modified engine oil also showed significant decreases in both wear and friction coefficients compared to the recommended concentrations. The addition of NPG Esters proves that the use of NPG Esters can increase the performance of commercial engine oils through improved tribological properties while also providing a sustainable and environmentally responsible choice for future lubrication applications.

Keywords: Calophyllum oil, motor bike engine oil, bio-lubricant, neopentyl glycol (NPG) esters

Cite this article as: Swathi, A., Chebattina, K. R., Vadapalli, S., Vemulapalli, V., Pathem, U. C., Pullagura, G., & Manoj, V. (2026). Analyzing neopentyl glycol ester blends for improvement of engine oil tribological properties. Journal of Thermal Engineering, 12(5), 1700–1710. https://doi.org/10.47481/jten.0059

1. Introduction

Lubrication plays a key role in the operation, longevity, and fuel efficiency of internal combustion engines in many high usage applications such as automotive and industrial machines. The four-cycle engine is the dominant engine design primarily due to its engineered efficiency and design versatility; however, the performance of the engine is highly dependent on the quality and performance of the lubricating oil used [1-3]. There is an increase in temperature, pressure, and constant mechanical friction associated with the harsh operating environment, demanding lubricants with very good tribological properties [4-5]. A basic understanding of tribology (study of friction, wear, and lubrication) is essential in the formulation and improvement of engine lubricants, since these performance factors directly affect engine wear rates, energy loss, and thermal performance. [7-9].

The importance of tribology to the operation of an engine oil is significant as tribology affects key operational characteristics of engine oil such as friction, wear, and temperature resistance. In a four-stroke engine, the proper lubrication between moving parts such as pistons, crankshafts, and valve assemblies has an important role in minimizing friction between those parts. High friction leads to a greater amount of fuel consumption, and a portion of the engine's parts may become worn in a way that will shorten the service life of the engine, increase maintenance costs, and possibly lead to complete engine failure. The

*Corresponding Author
E-mail Adress: swathi.090793@gmail.com

Submitted: 22 December 2024; **Accepted:** 26 June 2025

This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkılıç

Published by Yıldız Technical University, İstanbul, Türkiye

ideal engine oil will create a continuous lubricant film on the lubricating surfaces of the metallic parts it lubricates, preventing direct contact between metallic parts and, thus, reducing both friction and wear [10-12].

Also, engine oils need to preserve their properties under various working conditions, including high temperatures and variations in shear load, which may influence oil viscosity, film stability, and even the total protective function of the lubricant [13-15]. Conventional oils that degrade because of heat or loss of viscosity do not provide proper lubrication, which increases the likelihood of part failure. By addressing these tribological challenges, researchers and engineers may develop engine oils that not only prolong the life of the engine's parts but also enhance the efficiency and environmentally friendly operation of the engine [16-18].

Group V base oils are synthetic esters, and there are five different types of synthetic esters. They include monoesters, diesters, polyolesters, aromatic esters and complex esters. Of all the many kinds of organic esters, neopentyl polyolesters offer the best characteristics. Trimethylolpropane (TMP) esters, pentaerythritol (PE) esters and Neopentylglycol (NPG) esters are the three main categories of neopentyl polyolesters, which are synthetic esters with a quaternary carbon atom at the orthoposition of the ester group in their molecules. These polyesters have high flash points, low volatility, and exceptional thermal-oxidative stability help them in the automotive, marine and aerospace industries [6, 17-22].

This research evaluated the tribological performance enhancements of Commercial Engine lubricants blended with Neopentyl Polyol Ester (NPPE), considering earlier research from Table 1. The study quantitatively proves that when bio-based ester materials are blended into traditional lubricant formulations, friction, wear, and surface protection are all improved. The study shows that NPPE-Engine Oils have better anti-wear properties, a better film forming ability and improved stability under simulated engine conditions, which agrees with earlier studies on Polyol Ester – Motor Oil Blends and structural properties of Esters. Overall, the findings reinforce that NPPE–Engine Oil Blends are a good candidate for use in real-world automotive applications; moreover, they may also provide an avenue for sustainable, high-performance lubrication technologies.

Table 1. Condensed literature review and relevance to NPG ester–motor oil blends

Study Category / Focus	Application Area	Key Outcomes	Relevance to Present Study	Ref. No.
NPG ester synthesis and Calophyllum inophyllum oil	Bio-lubricants feedstock development	Successful ester production; appropriate fatty acid profile	Renewable base oil for current blend formulation	[1], [3]
Polyol ester blends with commercial motor oils	Lubrication system of the motorcycle engine	Enhanced tribological and corrosion properties	Direct basis for blending NPG-motor oil	[2], [9], [10]
Structure-property relationship of branched esters	Lubrication for industry and automotive applications	Branching enhances lubricity and thermal stability	Supports molecular design of NPG-ester	[4], [19], [29]
Eco-lubricants based on vegetable oils	Lubrication of engines in a sustainable way	Less reliance on mineral oil; green alternatives	Supports sustainability goal	[5], [7], [17]
Synthetic ester/PAO mixtures	High performance lubrication systems	Improved compatibility and wear mitigation	Supports blended with mineral oil	[6]
Test methods for tribological evaluation	Automotive and diesel engine oils	Standardized techniques for wear and friction analysis	Validated experimental procedure adopted	[14], [15], [22], [25]
Friction modifiers, ionic liquids & antioxidant additives	Additive technology for motor oils	Lower friction and better anti-wear performance	Benchmark comparison with traditional additive systems.	[11], [12], [28]
Nano-additive enhanced lubricants (MWCNT, ZrO2, Graphene, TiO2, SiO2, hybrid nano-lubes, carbon dots)	Nano-Modified lubrication of engine oil	Significant decrease in wear and rheological enhancement	Indicates possibilities for sophisticated improvement of NPG blends	[13], [16], [18], [24], [26], [27], [30]
Special Lubricating Compositions Oil Performance Studies	Diesel and IC engines	Better run-in efficiency and wear resistance	Make use under realistic engine conditions possible	[21], [23]
Biodiesel, emissions & performance studies	Diesel engine performance & sustainability	Reducing emissions and integrating renewable fuels	A wider perspective on green lubrication	[31]

Overall, this study is an important step forward in the development of green bio-lubricants based on polyol esters for providing long-term and sustainable solutions for lubrication. The results confirm that the use of bio-based esters as lubricant additives can lead to a reduction in friction and wear. These results support the suitability of bio-based esters to be used effectively as ethanol-based and vegetable oil-based lubricants and provide for the achievement of environmental sustainability aims. Such advancements reduce the need for petroleum-based lubricating additives and thus reduce the overall impact on the environment caused by petroleum- derived lubricants.

Using renewable feedstocks in making esters is helping to create cleaner and greener technology in the world. In addition, the continued development of bio-based polyol esters supports the move to create sustainable lubrication systems that allow engines to last longer and run better. The growing need for environmentally friendly alternatives has led to an increase in bio-lubricants offering high performance as a means of meeting energy sustainability issues and lessening the overall impact of climate change.

1.1. Present studies

In the present research project, blends of commercial motorcycle engine oil (having ZDDP) and bio-lubricant esters derived from Calophyllum inophyllum oil were characterized by their tribological properties. The motorcycle engine oils analyzed were commercially available lubricants having ZDDP as an anti-wear additive in four-stroke engine lubricants. The source of the bio-lubricant esters was Calophyllum inophyllum oil (commonly called Tamanu seed) which has a considerable content of oleic acid (>40%) and stearic acid (>18%), making it suitable for use as a renewable resource to produce bio-lubricant base stocks.

In synthesizing the NPG esters to evaluate the tribological performance of the blends, the interaction between the two types of bio-based polyol esters and the existing additive used in the commercial oil was considered. The blending process included evaluating various volume concentrations of 5%, 10%, 15%, 20%, 25% and 30% (v/v) to find the best blending percentage for the best overall tribological performance while achieving better lubrication properties than the commercial engine oil alone because of the performance enhancing additives.

The purpose of this study is to evaluate the use of NPG esters as a bio-based additive to four-stroke motor bike engine oils to enhance friction reduction and wear resistance. All tribological tests were performed using a four-ball tester under controlled operating conditions. The four-ball testing simulates the boundary lubrication conditions that would exist in the four-stroke engine using three stationary balls and one rolling ball, creating a three-point contact point at the interface of the test sample and the ball to create an environment that allows for an assessment of the anti-wear and friction-reducing characteristics through the measurement of the wear scar diameter and coefficient of friction obtained from each sample.

2. Methodology

2.1. Materials used

The investigations began by extracting oil from Calophyllum seeds available in GITAM (Deemed to be University) in Visakhapatnam, which was selected for their high oil content. The seeds were prized owing to their inherent qualities. Key chemicals, including neopentyl glycol (NPG), were bought from ACRO Organics, a recognized supplier in India, as fundamental ingredients for synthesizing the desired polyol esters. For extraction and purification, high-quality solvents and reagents such as hexane, aluminum oxide, toluene, and ethyl acetate were acquired from Finar, a recognized source in India. Chromatographic silica gel was obtained from Fisher Scientific in Ahmedabad, India. The specialized chemical reagents (chemical stimulants) that will be used to manufacture and purify polyol esters, such as hydrochloric acid, sodium thiosulfate, sodium sulfate and bases, were obtained from Fisher Scientific in Mumbai, India. These special reagents are critical to both the synthesis and purification of polyol esters due to being able to provide the necessary purity and chemical composition of the finished polyol esters.

p-TSA (p-toluenesulfonic acid) is a strong Lewis acid that eases the acceleration of chemical reactions The p-TSA was obtained from AVRA Labs in Hyderabad, India, who is known for supplying high-quality chemicals. All of the solvents, reagents and compounds used in the current studies are of analytical grade and have a minimum standard for purity, therefore, allowing the solvents, reagents and/or compounds to be added directly into the studies without the necessity of undergoing any dialogue processes to further purify these solvents, reagents or compounds prior to their addition. Our continuing commitment to having high-quality materials in our studies provides validity and repeatability to our research efforts aimed at synthesizing bio-based polyol esters from calophyllum seeds and the use of neopentyl glycol as the primary precursor. The systematic method for finding and obtaining high-quality raw materials from reputable suppliers is the foundation upon which an experimental framework has been developed to provide a correct and reliable bio-based polyol ester produced from calophyllum seeds.

2.2. Analytical techniques

Analytical methods using ultramodern equipment were performed. The gas chromatographic (GC) analysis was conducted with the use of Agilent model 6890 N series with a flame ionization detector. The nuclear magnetic resonance (NMR) spectroscopy was carried out on an Avance 300 MHz spectrometer in CDCl3, with the chemical shifts referenced to tetramethylsilane (TMS) as an internal standard. Infrared (IR) spectra were also collected with a Perkin-Elmer model 1600 FT-IR Spectrometer [7].

2.3. Oil extraction procedure

Oil is extracted from the calophyllum kernel by first cooling and grinding it finely. Using a soxhlet extractor, oil is extracted using hexane as a solvent and evaporated under vacuum until about 40% of oil (crude oil) stays. Further work can then be carried out on the crude oil without any other purification steps being performed [9].

2.4. Preparation of calophyllum fatty acid

The synthesis of calophyllum acid (CFA) is well documented in the literature. A mixture of 300 g calophyllum oil and 54 g sodium hydroxide (NaOH) dissolved in 675 ml HgO was stirred for about four hours (i.e. until completion) at an elevated temperature (80–90°C). The progress of the molecular reaction was checked by using thin-layer chromatography (TLC) with a mixture of hexane and ethyl acetate (90:10, v/v) as a mobile phase until complete conversion to sodium calophyllate was shown by the absence of any triglycerides on the TLC plate.

After the experiment was finished, the reaction vessel was cooled to 50°C, the mixture was neutralized with concentrated HCl, washed with distilled water (twice), concentrated (under vacuum), and then extracted with ethyl acetate (EtOAc) dilute (2% solutions), and a total of 270 g of CFA was obtained with a semisolid consistency over the required range after evaporation.

^{1}H NMR (in $CDCl_3$, δ ppm):

- 0.85 (t, -CH3): A triplet (t) at 0.85 ppm corresponds to a methyl group (-CH3).
- 1.20-1.24 (m, (-CH2-) n): Several (-CH2-) groups in different chemical environments give a multiplet (m) at 1.20-1.24 ppm.
- 2.02 (m, CH2-C=C): A multiplet at 2.02 ppm shows methylene groups next to a double bond (CH2-C=C).
- 2.25 (t, -CH2C=O): A triplet at 2.25 ppm is characteristic of a methylene group attached to a carbonyl group (-CH-2C=O).
- 5.29 (m, CH=CH-): A multiplet at 5.29 ppm confirms the existence of a double bond (CH=CH-).

IR (neat, cm^{-1}):

- 3583 (OH): An absorption band at 3583 cm^{-1} suggests the presence of an alcohol group (-OH).
- 3056 (CH=CH): Presence of double bond (CH=CH) absorption peak at 3056 cm^{-1}.
- 2859 (CH3): An absorption band at 2859 cm^{-1} is indicative of methyl groups.
- 1712 (C=O): The intense absorption band at 1712 cm^{-1} corresponds to a carbonyl group (C=O). This indicates the presence of a ketone or an aldehyde.

2.5. Preparation procedure – Calophyllum neopentyl glycol ester

Fatty acids of Calophyllum (170 g, 0.6048 mol), neopentyl glycol (30 g, 0.288 mol) and p-TSA (2 g, 1% w/w fatty acids) formed under reflux while being mixed and stirred with 200 ml toluene. The water produced from the reaction was collected in a Dean Stark apparatus while following the progress via TLC with a hexane to ethyl acetate solvent system (9:1). When all the fatty acid was no longer visible, toluene evaporated off under vacuum and cooled to room temperature. Next, a solution of sodium bicarbonate was mixed with ethyl acetate, and the solution was stirred for 30 minutes. The two-phase mixtures were separated, and the organic phase was washed twice with water, dried with anhydrous sodium sulfate, and then concentrated under vacuum. Finally, the crude ester was purified by column chromatography on basic alumina, eluent: 95% hexane/5% ethyl acetate.

^{1}H NMR ($CDCl_3$, δ ppm):

- 0.90 (t, -CH3): This shows the presence of a triplet (t) at a chemical shift of 0.90 ppm, typical of a methyl group (-CH3).
- 1.15-1.4 (m, (-CH2-) n): This is a multiplet (m) between 1.15 and 1.4 ppm, corresponding to a series of methylene groups (-CH2-) in different surroundings.
- 2.06 (m, CH2-C=C): multiplet at 2.06 ppm, representative of methylene groups attached to a double bond (CH2-C=C).
- 2.39 (t, -CH2C=O): This is a triplet at 2.39 ppm showing a methylene group next to a carbonyl group (-CH2C=O).
- 4.07 (s, CH2-O-C=O) : This is a singlet (s) at 4.07 ppm showing a methylene group next to an ether linkage or an ester group (CH2 -O - C=O).
- 5.33 (m, CH=CH-): A multiplet at 5.33 ppm is indicative of a double bond (CH=CH-).

IR (neat, cm^{-1}):

- 2925 ($-CH_2$): The absorption band at 2925 cm-1 is characteristic of methylene groups.
- 2855 (CH_3): The presence of methyl groups is shown by this absorption band at 2855cm^{-1}.
- 1743 (C=O): The intense absorption band at 1743 cm^{-1} assigned to a carbonyl group (C=O) suggests the presence of an ester or ketone.
- 1168 (COC): The absorption band at 1168 cm^{-1} is typical for ether linkages (COC).

This method provides a systematically controlled method for production of bio-lubricants from calophyllum inophyllum oil. It is also used to prove that renewable resources can be used in place of traditional mineral based lubricants that are not environmentally friendly. The esterification reaction was done under controlled reflux conditions, and the product was purified through a column chromatography, yielding very pure esters suitable for use as lubricants.[1,3] The structure of the product and the properties of the product have been confirmed by ^{1}H NMR and FTIR; therefore, the functional groups and molecular structures can be properly identified through these methods. This complete synthesis method and characterization have been outlined in Figure 1.

2.6. Testing of tribological properties

ASTM D4172 specifies how to break three balls, that have been stationary on the bottom of a ball pot and one of which has been loaded and spun on a top ball, to create a wear scar when the water-based lubricating medium breaks down. More specifically, it requires measuring the size of the wear scars on the three bottom balls, averaging them, and calculating the wear scar diameters.

The friction test is performed following the recommendation of ASTM D 5183, which simulates an internal combustion engine, or I.C.E., under multiple load conditions. Prior to conducting the friction test, a first break in is completed; after completing the first hour-long break in, the previously used lubricating oil is removed from the test and the ball pot is cleaned, however, the previously broken balls stay in the ball pot. The sample quantity of lubricants for the friction test is 10 ml. The starting load for the friction test is set up at 98.1 N and continues to increase by 98.1 N increments every 10 minutes until a rapid increase in friction torque is seen, showing a seizure.

Table 2. Wear and friction Test conditions for evaluating lubricant on a four-ball tribometer

	Wear test as per ASTM D 4172	
S.No	Parameter	Range
1	Temperature	75
2	Test Duration	1 h
3	Speed	1200 RPM
4	Load	40kgf
	Friction Test as per ASTM D 5183	
1	Temperature	75
2	Test Duration	1 h (wear-in) Followed by friction test up to seizure load
3	Speed	600 RPM
4	Load	40kgf (Stepwise load friction testing from 10 kgf, raised by 10 kgf every 10 minutes up to seizure load

3. Results and discussions

By applying an aqueous sodium hydroxide solution, Calophyllum seed oil underwent a conversion process, resulting in the extraction of its fatty acid components. The composition of these fatty acids was meticulously decided using Gas Chromatography (GC) and is comprehensively outlined in Table 2.

Table 3. Composition of fatty acids in Calophyllum oil

S.No	Fatty acids	Compositions
1.	Palmitic (16.0)	15.23%
2.	Stearic (18.0)	15.93%
3.	Oleic (18:1)	37.57%
4.	Linoleic (18:2)	27.78%
5.	Others	3.50%

Esterification of fatty acids from Calophyllum inophyllum seed oil using several polyhydric alcohols (i.e. trimethylolpropane, neopentyl glycol, and pentaerythritol) occurred catalytically when p-toluene sulfonic acid (p-TSA) was used as a catalyst. The reaction mixture was refluxed overnight while simultaneously removing the water produced during the reaction continuously using a Dean-Stark apparatus forcing the reaction to completion. Thin-layer chromatography (TLC) was then used to check the reactions and confirm the formation of the corresponding esters. At the end of the reaction, the reaction mixture was neutralized by a sodium bicarbonate/ethyl acetate system separating the layers. Following this, the organic layer of the reaction was collected and concentrated under reduced pressure. The detailed reaction conditions and yield data are presented in Table 3. Following concentration of the crude esters, each product underwent purification via column chromatography as described in Scheme-1. The synthesized esters were very fragrant and characterized by 1H-NMR and IR spectroscopy. The presence of the ester group was confirmed by the presence of IR peaks (-C=O) at 1735 cm-1 and multiple 1H-NMR peaks.

All pre-formed esters were shown to have a density value of 0.9263g/cc - 1.072g/cc. The increasing density of the esters after esterification and the higher chain lengths show that the esters can be used as potential lubrication oils based on this same density. The kinematic viscosity of the esters created from neopentyl glycol, trimethylol propane, and pentaerythritol were 6.8 cSt,8.87 cSt, & 9.3 cSt at 40 degrees celsius (°C), respectively. The kinematic viscosity of these same three esters as measured at 100 °C range from 1.42 cSt - 3.01 cSt. All the three polyol esters had relatively high viscosity indices (>200), which supports the stated use of these materials as possible lubrication oils. The pour points of polyol esters made from neopentyl glycol ester are excellent at -16°C, showing that the polyol esters have good low temperature flow properties and are therefore very good candidates for use as bio-lubricants. Finally, all four polyol esters had flash and fire points above 192 and 198°C, respectively, which shows they are very stable and safe for use as a lubricant oil. The products were also very low in corrosiveness, showing their suitability with many materials.

Finally, synthetic polyol esters (from fatty acids of Calophyllum) could be a possible source of bio-lubricant additives due to superior performance tribologically. Results confirm greater friction by reducing properties combined with increased anti-wear ability and effective surface protection when blended with motorbike engine oil support their suitability for use in practical lubrication applications where wear/reduction of energy losses caused by friction is critical.

Esters used in tests greatly improved lubrication efficiency based on blending ratios. The extent of performance increase from adding esters made from non-edible Calophyllum oil shows they can be acceptable sustainable replacements for traditional petroleum-based additives. As shown in this study, esters effectively reduced friction and wear without sacrificing lubricant stability; hence, these projects will ease future growth into practical engine environments.

This research has created new possibilities for creating renewable, non-edible oil bio-lubricants that are designed specifically to improve tribological properties. This research enhances the anti-wear performance and reduces the friction of these bio-based lubricants, therefore enhancing the environmental benefits of lubrication strategies. Bio-based materials can be a way for the world to move from fossil fuel-based lubricants to a sustainable energy future.

In general, this is a novel and important step forward in the development of green lubrication technologies. The tribological properties shown by Calophyllum based polyol esters suggest their potential as ingredients in the development of next generation bio-lubricants which will contribute to better engine durability, efficiency and lower environmental impact.

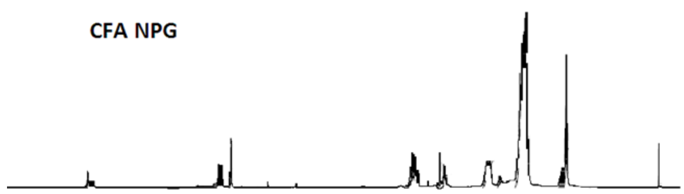

Figure 1. ^{1}H NMR of calophyllum ester of NPG ester

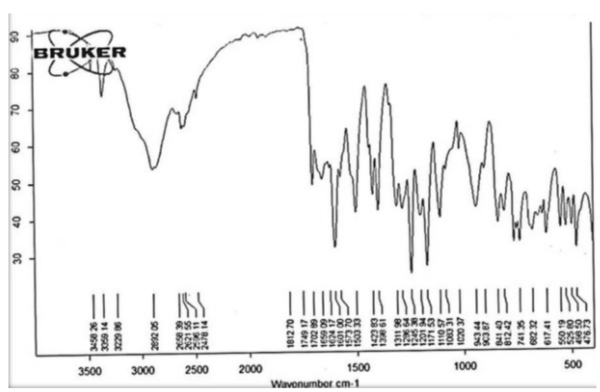

Figure 2. IR of calophyllum NPG, PET and TMP esters respectively

A bio-lubricant stock derived from Neopentyl Glycol (NPG) is combined with commercial oil at volume percentages of 5%, 10%, 15%, 20%, 25%, and 30%. The test oils that are produced are then analyzed for their tribological characteristics to find the best blend ratio.

3.1. Tribological properties

A total of ten tribological tests were conducted to confirm the wear performance results, with average wear scar values calculated for each experimental group to ensure reliability and repeatability. The analysis of the wear data revealed that the synergistic effect of neopentyl glycol (NPG) combined with the additive package present in the commercial engine oil significantly improved the tribological performance of the tested formulations as summarized in Table 4. The wear tests were carried out according to ASTM D4172 with applied loads of 392.4 N (40 kgf) and 588 N (60 kgf). The results showed that the NPG having blends had significant improvements over the neat commercial oil under both load conditions. It was found that the blending concentrations up to 15% NPG resulted in the best performance, while higher blending concentrations of 20% NPG showed a gradual decrease of the tribological performance. The variation in wear behavior with respect to blend composition and applied load is illustrated in Figure 2.

Additionally, as clearly shown in the friction tests, the addition of NPG to commercial oil at a rate of no more than 15 % provides premium protection against wear and reduces the overall friction of the tested oils. This is attributed to the lower coefficient of friction (CF) presented by the ester part when compared to the commercial oil. Ultimately, the degree of protection and reduction of friction experienced by the tested composites could be due in large part to the amount of frictional load applied when conducting these tests.

The outcomes of the friction tests are presented as the coefficient of friction and seizure load for different test oils in Figs. 4 and 5. The graph shows a positive trend when commercial oil is mixed with NPG, with the best performance achieved at the 15% mixing ratio. Beyond this point, the effectiveness begins to decline, highlighting the significance of keeping a proper concentration to maximize the tribological benefits of the lubricant.

Table 4. Results of tribological (Wear) test of oils

Test Oils	Wear Te Wear scar diameter, microns 40kgf	 60kgf
NPG (bio lubricant)	672.4	1005.2
Commercial oil	408.58	494.35
Commercial oil + 5% bio lubricant	406.57	490.59
Commercial oil + 10% bio lubricant	403.32	488.15
Commercial oil + 15% bio lubricant	401.81	484.43
Commercial oil + 20% bio lubricant	406.66	489.71
Commercial oil + 25% bio lubricant	410.71	495.34
Commercial oil + 30% bio lubricant	415.45	513.15

Table 4 shows the results from a wear test using a selection of lubricants at both 40 kgf, and 60 kgf, under load. The lubricants were either NPG (a bio lubricant), commercially available (oil), or commercially available (oil) blended with various percentages of the bio lubricant. The wear scar diameter (microns) is displayed in the table to show the wear resistance of the lubricants for each load condition tested. The table is laid out in a way to prove both the various types of lubricants and the wear scar diameter values for each respective lubricant and loading conditions.

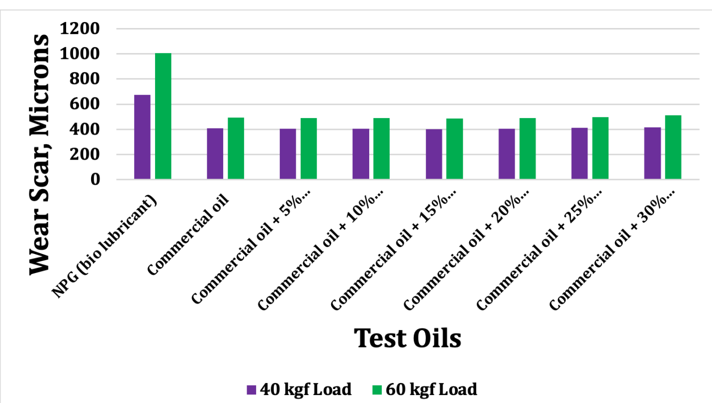

Figure 3. Variation of wear scar diameter with wear test of commercial oil plus NPG ester blends for 40kgf and 60kgf respectively

The goal of this research was to evaluate the wear properties of different lubricants based on two different mechanical loads, one at 40kgf (392.4N) and one at 60kgf (588N), to decide how well the lubricants perform when subjected to different amounts of mechanical stress. This provided an overall evaluation of the lubricant's load-carrying abilities and how resistant they would be to wear depending on the mechanical load conditions. The bio-lubricant product Neopentyl Glycol (NPG) was evaluated separately from the commercial engine oil to decide its tribological properties. The commercial engine oil was used as a baseline for all the data collected, as it is the standard lubrication system in use today. NPG was blended with commercial oil so there were six concentrations used: 5%, 10%, 15%, 20%, 25% and 30% by volume. These concentrations of NPG and commercial engine oil were then tested to decide the effect of NPG on the wear of the lubricant. Figure 3 shows the performance data for each of the two mechanical load conditions on the lubricants.

The wear scar diameter (WSD) is a way of measuring how much wear has occurred on the surface and thereby provides a means of deciding how well the lubricant formulations resist wear. Anti-wear performance and load-carrying capability of lubricants are enhanced if the wear scar diameter is smaller. The blended formulation having 15% bio-lubricant and commercial engine oil produced lower wear scar diameters consistently across all tests in Table 5, showing that the formulation has better wear resistance than the other formulations tested. These results support the conclusion that the optimized blend composition will perform to specification in the testing conditions described.

Table 5. Results of tribological (Friction) test of oils

Friction Test		
Test Oils	Friction coefficient	Seizure load, N
NPG (bio lubricant)	0.0724	891.4
Commercial oil	0.0992	1186.1
Commercial oil + 5% bio lubricant	0.0983	1187.8
Commercial oil + 10% bio lubricant	0.0974	1189.2
Commercial oil + 15% bio lubricant	0.0965	1225.7
Commercial oil + 20% bio lubricant	0.0982	1211.4
Commercial oil + 25% bio lubricant	0.1055	1095.2
Commercial oil + 30% bio lubricant	0.1243	1094.6

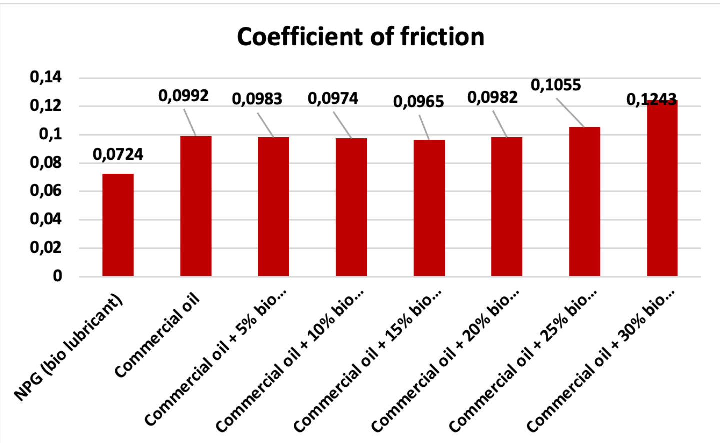

Figure 4. Variation of coefficient of friction with commercial oil plus NPG ester blends

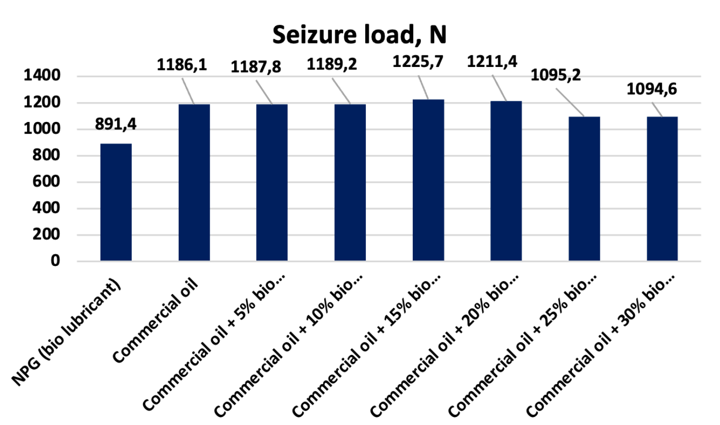

Figure 5. Variation of seizure load with friction test done on blends of commercial oil plus NPG ester

This friction test was carried out using multiple commercial lubricant formulations to evaluate the coefficient of friction and seizure load for test specimens made from 0.307N oil and NPG bio lubricant mixtures at the following proportions: (a) 5% bio lubricant; (b) 10% bio lubricant; (c) 15%; (d) 20%; (e) 25%; (f) 30%. In this comparison, the following results were recorded for each sample:

Coefficient of Friction - The coefficient of friction measures friction resulting from contact between surfaces. A lower coefficient value is a smoother lubricant and decreasing friction. Seizure Load the largest amount of load applied to the surface before seizure (during an overload) or the friction-related failure of the surface.

Commercial oil is a commercial lubricant to compare results to the bio lubricant. The commercial oil blended with each percentage of bio lubricant was tested during this trial and the following results were recorded: 0.0965 for the 15%-bio blended lubricant is the lowest coefficient of friction and 1225.7 N (275.6 lbs.) is the largest seizure load. The results show a significant performance difference in the reduction of friction and prevention of seizure with the use of the commercial oil blended with 15% bio lubricant.

A concentration of 15% bio-based lubricant produces a lower coefficient of friction (0.0965) providing for smoother lubrication and after less resistance between two surfaces. Moreover, the mixed lubricant with 15% bio-based lubricant shows a relatively high seizure load (1225.7 N) showing a lower resistance to friction failure than lubricants with no bio-based products. Thus, the 15% bio-based lubricant interacts in a balanced way with commercial oil, leading to optimized lubricating properties and less friction problems. The combination of commercial oil with the 15% bio-based lubricant may provide a synergistic effect whereby each individual component's specific characteristics work together to build a more effective overall lubricant.

4. Conclusion

This study used experimental methods to decide the feasibility of using neopentyl glycol (NPG) as a bio-lubricating additive in the enhancement of tribological performance characteristics of engine oils used by motorcycles. The study proved that when NPG was added to an existing bulk lubricant at various concentrations (5% to 30% of NPG) there was a substantial improvement in the antiwar characteristics and the coefficient of friction associated with the bulk lubricant used in motorcycle engines. Additionally, the experimental data from this study suggest that the bio-lubricant formulations formed from these mixtures show superior boundary lubricating properties when compared to fast moving bulk motorcycle engine oils available for sale, which can be classified as conventional lubricants. The improvement of friction and wear coefficients associated with increasing concentrations of NPG shows an increase in performance of lubricity and protective qualities associated with the bulk lubricant. In addition, the study revealed that higher concentrations of NPG than the recommended blend levels will produce decreases in both viscosity and viscosity index. Although added additions of NPG to bulk lubricant improve the tribological performance of the lubricant, it is important to keep a stable ratio of the overall lubricant blend to keep performance and stability.

Of all the different blends of motor bike engine oil tested, the most well-rounded blend that provided best performance was the one that had 15% NPG ester. This blend showed considerable reduction in friction and minimized the amount of wear scar formation in addition to proving stable lubrication under the specific test conditions. No matter how you look at it, the 5% blend showed improved low-temperature flow characteristics, and the 20% blend provided the most stable viscosity properties; however, the 15% blend showed the largest amount of tribological improvement for the lowest amount of compromise about lubricant consistency.

In summary, the use of an NPG ester derived from Calophyllum oil blended with motor bike engine oil is a sustainable and high-performance alternative to traditional petroleum-based additives. The improved friction reduction and wear resistance characteristics prove to have excellent potential for immediate application in engines. Therefore, this research supports the continued development of eco-friendly lubrication systems that increase engine longevity and eco-friendly energy use, while decreasing the overall negative impact on the environment.

Acknowledgments

We thank the Department of Mechanical Engineering and Department of Chemistry, GITAM (Deemed to be University), for allowing us to conduct research. This work was ostensibly supported by the Department of Science and Technology under the Technology System Development Programme (TSDP) Government of India, project no “DST/TSG/AF/2014/01”. Department of Lipid Science and Technology, Hyderabad IICT is acknowledged for 1H NMR, GC and IR spectral data.

Author contributions statement

Akula Swathi and Kodanda Ramarao Chebattina conceived and designed the study and developed the research method. Akula Swathi, Srinivas Vadapalli, and Uma Chaithanya Pathem carried out experimental work, collected the data, and performed the analysis. Vandana Vemulapalli and Gandhi Pullagura contributed to the interpretation of the results, literature review, and critical revision of the manuscript. Kodanda Ramarao Chebattina and Vasupalli Manoj supervised the research, offered technical guidance, and reviewed the manuscript.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used Grammarly solely to improve grammar, spelling, punctuation, and language clarity. The tool was not used to generate scientific content, interpret results, or draw conclusions. All scientific content, analyses, interpretations, and conclusions were developed by the authors.

References

[1] Vandana, V., Kodanda, R. R. C. H., Somnath, G., & Babia, L. (2017). Synthesis of esters as biofuel Calophyllum inophyllum feed stock. JOJ Material Science, 2(2), 555–583.

[2] Srinivas, V., Chebattina, K. R., Pranay, G. V. S., Lakkoju, B., & Vandana, V. (2020). Tribological properties of polyol ester–commercial motorbike engine oil blends. Journal of King Saud University - Engineering Sciences, 34(1), 57–66. https://doi.org/10.1016/j.jksues.2020.07.004

[3] Babi, L., & Vandana, V. (2022). Preparation and properties of bio-lubricants of neopentylglycol esters from various acids. Research Journal of Chemistry and Environment, 26(1), 9–18. https://doi.org/10.25303/2601RJCE0918

[4] Eychenne, V., & Mouloungui, Z. (1998). Relationships between structure and lubricating properties of neopentylpolyol esters. Industrial & Engineering Chemistry Research, 37(12), 4835–4843. https://doi.org/10.1021/ie9801204

[5] Bekal, S., & Bhat, N. R. (2012). Bio-lubricant as an alternative to mineral oil for a CI engine—An experimental investigation with Pongamia oil as a lubricant. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 34(11), 1016–1026. https://doi.org/10.1080/15567031003735303

[6] Jiang, S., Li, S., Liu, L., Wang, L., & Mominou, N. (2015). The tribological properties and tribochemical analysis of blends of poly alpha-olefins with neopentyl polyol esters. Tribology International, 86, 42–51. https://doi.org/10.1016/j.triboint.2015.01.015

[7] Heikal, E. K., Elmelawy, M. S., Khalil, S. A., & Elbasuny, N. M. (2017). Manufacturing of environment friendly biolubricants from vegetable oils. Egyptian Journal of Petroleum, 26(1), 53–59. https://doi.org/10.1016/j.ejpe.2016.03.003

[8] Priyadharshan, J. S. P., Srinivas, V., Chebattina, K. R., Vandana, V., & Subrahamanyam, P. V. (2019). Tribological characteristics of epoxide-based bio lubricant - Commercial gear oil blends. IOP Conference Series: Materials Science and Engineering, 653(1), 012041. https://doi.org/10.1088/1757-899X/653/1/012041

[9] Chebattina, K. R. R., Srinivas, V., Pranay, G. V. S., Krishna, P. V., & Priyadharshan, J. S. P. (2019). Tribological characteristics of Calophyllum ester-based bio-lubricant - Commercial engine oil blends. IOP Conference Series: Materials Science and Engineering, 653(1), 012013. https://doi.org/10.1088/1757-899X/653/1/012013

[10] Rao, B. K., Chebattina, K. R. R., Srinivas, V., Srikar, M. S., Bhanuteja, S., Challa, B., Usanova, K. I., & Saxena, A. K. (2024). Physicochemical and corrosion properties of polyol ester-commercial motorbike oil blends. Cogent Engineering, 11(1). https://doi.org/10.1080/23311916.2024.2390690

[11] Yang, Z., et al. (2022). Tribological performance study of oil-soluble ILs as lubricant additives by the four-ball method. Lubrication Science, 35(3), 183–192. https://doi.org/10.1002/ls.1605

[12] Dubey, M. K., et al. (2022). Tribological evaluation of passenger car engine oil: Effect of friction modifiers. Results in Engineering, 16, 100727. https://doi.org/10.1016/j.rineng.2022.100727

[13] Nabhan, A., Rashed, A., Taha, M., Abouzeid, R., & Barhoum, A. (2022). Tribological performance for steel–steel contact interfaces using hybrid MWCNTs/Al2O3 nanoparticles as oil-based additives in engines. Fluids, 7(12), 364. https://doi.org/10.3390/fluids7120364

[14] Juostas, A., Jotautienė, E., & Greco, C. (2021). Experimental evaluation of the tribotechnical properties of engine oils for combine harvesters. Journal of Friction and Wear, 42(1), 11–16. https://doi.org/10.3103/S1068366621010091

[15] Bąkowski, H. (2022). The complete approach to the impact of selected lubricating additives on the tribological properties of engine oils by means of a partial experimental design. Tribologia, 300(2), 7–13.

[16] Kuti, R., Szabó, Á. I., & Tóth, Á. D. (2022). Experimental investigation of tribological properties of two fully formulated engine oils with additional nanoscale spherical zirconia particles. Lubricants, 10(10), 246. https://doi.org/10.3390/lubricants10100246

[17] Basiron, J., Abdollah, M. F. B., Abdullah, M. I. H. C., & Amiruddin, H. (2023). Formulation and tribological performance of engine oil blended with various non-edible vegetable oils. Lubrication Science, 35(7), 480–497. https://doi.org/10.1002/ls.1635

[18] Alqahtani, B., et al. (2022). Tribological performance and rheological properties of engine oil with graphene nano-additives. Lubricants, 10(7), 137. https://doi.org/10.3390/lubricants10070137

[19] Zulfattah, Z. M., et al. (2020). Friction and wear performance of oleate-based esters with two-, three-, and four-branched molecular structure in pure form and mixture. Journal of Tribology, 143(1). https://doi.org/10.1115/1.4047874

[20] Kumar, N., & Goyal, P. (2022). Experimental study of carbon nanotubes to enhance tribological characteristics of lubricating engine oil SAE10W40. IOP Conference Series: Materials Science and Engineering, 1225(1), 012052. https://doi.org/10.1088/1757-899X/1225/1/012052

[21] Cyriac, F., Tee, X. Y., Poornachary, S. K., & Chow, P. S. (2020). Influence of structural factors on the tribological performance of organic friction modifiers. Friction, 9(2), 380–400. https://doi.org/10.1007/s40544-020-0391-6

[22] Kuti, R., Könczöl, F., Csapó, L., Papp, C., Földi, L., & Tóth, Á. D. (2024). Selection of engine oils with tribological examinations applicable to specially operated diesel engines. FME Transactions, 52(2), 335–342. https://doi.org/10.5937/fme2402335K

[23] Zhiltsov, S. N., Cherkashin, N. A., Guzhin, I. N., Prikazchikov, M. S., & Khokhlov, A. L. (2022). Application of special lubricating compositions to increase the efficiency of friction surface run-in. BIO Web of Conferences, 52, 00031. https://doi.org/10.1051/bioconf/20225200031

[24] Hamisa, A. H., Azmi, W. H., Ismail, M. F., Rahim, R. A., & Ali, H. M. (2023). Tribology performance of polyol-ester based TiO_2, SiO_2, and their hybrid nanolubricants. Lubricants, 11(1), 18. https://doi.org/10.3390/lubricants11010018

[25] Skonieczna, D., Vrublevskyi, O., & Szczyglak, P. (2023). Evaluation of the antiwear properties of timely changed engine oils. Silniki Spalinowe/Combustion Engines, (July). https://doi.org/10.19206/CE-166274

[26] Hong, Y., Mo, Y., Lv, J., & Wang, J. (2023). Tribological properties of polymer friction improvers combined with MoDTC/ZDDP at different temperatures. Lubricants, 11(5), 196. https://doi.org/10.3390/lubricants11050196

[27] Del Río, J. M. L., Rial, R., Nasser, K., & Guimarey, M. J. G. (2023). Experimental investigation of tribological and rheological behaviour of hybrid nanolubricants for applications in internal combustion engines. Tribology Letters, 71(1). https://doi.org/10.1007/s11249-023-01683-1

[28] Jin, Y., et al. (2022). Preparation and performance evaluation of an ester-bridged antioxidant used as multifunctional additive in ester oil. Lubrication Science, 34(5), 347–355. https://doi.org/10.1002/ls.1592
[29] Tang, W., Zhu, X., & Li, Y. (2021). Tribological performance of various metal-doped carbon dots as water-based lubricant additives and their potential application as additives of poly(ethylene glycol). Friction, 10(5), 688–705. https://doi.org/10.1007/s40544-020-0487-z.
[30] Chand, S. M., Prakash, J. O., & Rohit, K. (2024). Impact of biodiesel blends on performance, emissions and waste heat recovery of diesel engine driven cogeneration system. Journal of Thermal Engineering, 680–696. https://doi.org/10.14744/thermal.0000819
[31] Sekharraj, K., Balu, P., Ravisankar, R., & Saravanan, A. M. (2024). An experimental assessment of performance and emission analysis on a green microalgae biodiesel di engine with Bi2O3 nanoparticles. Journal of Thermal Engineering, 904–910. https://doi.org/10.14744/thermal.0000839