ISSN: 3064-6758 www.aristonpubs.com/sciengg-advances https://doi.org/10.69626/sea.2024.0158

RESEARCH ARTICLE

Tribological Evaluation of Engine Oil Blended with Sesame, Mustard, and Olive Oils as Additives

Md. Sharique Azmi, Sabah Khan, Ali Saleh Hussein Alqushaibi

ABSTRACT: Friction and wear significantly impact the efficiency, performance, and lifespan of mechanical systems, underscoring the importance of high-performing lubricants. This study investigates the tribological performance of engine oil (5W-40) blended with 10% volume fraction of three vegetable oils—sesame oil, mustard oil, and olive oil. The vegetable oils were selected for their natural lubricating properties and sustainability. Blends were prepared using a magnetic stirrer at 1200 rpm for 45 minutes at room temperature. A Linear Reciprocating Tribometer (LRT) was used to evaluate the coefficient of friction (COF) and friction factor (FF) of the blends. Among the tested samples, sesame oil showed the most promising results, reducing the COF to 0.35 and FF to 7.13. Olive oil and mustard oil blends followed, with COF values of 0.37 and 0.38, and FF values of 7.42 and 7.68, respectively. The base oil (5W-40) without additives exhibited a COF of 0.36 and FF of 7.24. The superior performance of sesame oil is attributed to its chemical composition, which likely enhances boundary lubrication and film formation at contact surfaces. Olive oil showed moderate improvements, while mustard oil exhibited the least effective friction-reducing properties among the three additives. These findings suggest that sesame oil holds significant potential as a sustainable and effective lubricant additive. Future research should focus on optimizing additive concentrations, analyzing long-term stability, and exploring performance under varying operational conditions to maximize the benefits of natural oil additives in lubrication systems.

Keywords: Tribological Properties, Vegetable Oil Additives, Friction and Wear Reduction, Synthetic Lubricants.

Received: 13 July 2024; Revised: 30 August 2024; Accepted: 23 September 2024; Available Online: 19 October 2024

1. INTRODUCTION

In the modern world, lubrication, friction, and material wear all have an increasing impact on the longevity and efficiency of machinery [1-3]. Friction is considered to be responsible for 20% of the world's energy consumption [4-6], even while it is not necessarily unwanted, as in the cases of machining, manufacturing, and grinding. Growing reliance on non-renewable energy sources like coal and petroleum raises questions about the necessity of lowering friction in the industrial and transportation sectors [7]. Controlling wear and friction by using lubricants and the use of suitable lubricants is one of the greatest ways to avoid or minimize the effects of friction because these methods not only greatly increase energy efficiency but also lower CO_2 emissions [4].

Consequently, it is crucial to find and create superior lubricant materials to reduce the removal of material commonly known as wear and lower the value of coefficient of friction. Researchers working on lubricants are interested in working to enhance the tribological performance of lubricants. There have been reports of several techniques with which researchers try to enhance the tribological properties of lubricants, including vegetable oils. Normally vegetable oils have efficient lubrication properties, for instance, they have low volatility, they have a natural lubricity quality, they have high viscosity index, non-toxic and they can easily mix with other fluids [1]. The increased

Department of Mechanical Engineering, Jamia Millia Islamia University, New Delhi, India

* Author to whom correspondence should be addressed: shariqazmi31@gmail.com (Md. Sharique Azmi)

demand for materials that are biodegradable in nature has led to fresh avenues for using vegetable oils as a substitute to mineral oil lubricants [2], mainly in running machines, which shows anti-friction and anti-wear behavior when used as additives in conventional lubricants [3]. Addition of additives which have anti-wear and anti-scuffing properties is one of the very common ways to enhance the tribological properties of any lubricants [8]. In order to make lubricants more and more efficient a variety of additives have been taken for searching for better results, some of vegetable oils are Sesame oil, Olive oil and Mustard oil which has been used as additives in this research experiment. Different sorts of lubricity can be enhanced, depending on the additives' makeup and type.

Engine Oil: The base oil utilized in this investigation was Castro 5W-40 motor oil. A local retailer in Delhi purchased it. Engine oil 5W40 is a fully synthetic or semi-synthetic multigrade lubricant utilized in internal combustion engines, especially in contemporary automobiles, trucks, and SUVs. The Society of Automotive Engineers (SAE) has developed a numerical coding system for classifying motor oils based on their viscosity properties. Multigrade oils were created to offer protection across varying temperatures due to the temperature-dependent viscosity of oil [9]. This explains the presence of the designation SAE 5W-40 on the label. The "5W" denotes the oil's viscosity at low temperatures. The "W" signifies "winter," while the number 5 denotes the oil's viscosity at low temperatures. A reduced viscosity indicates that the oil flows more readily at low temperatures, facilitating effective lubrication during engine initiation, particularly in frigid environments [10]. The "40" denotes the oil's viscosity at standard operating temperatures (around 100°C). It demonstrates the oil's capacity to sustain a denser protective layer at elevated temperatures, which is crucial for lubricating high-stress engine components such as the pistons and crankshaft. The majority of 5W40 oils are totally synthetic, indicating they are composed of chemically formulated base oils intended to deliver enhanced protection, stability, and performance relative to conventional lubricants.

Synthetic oils provide superior performance in severe temperatures and offer prolonged lubrication. Semi-synthetic: In certain instances, 5W40 oil may be semi-synthetic, combining synthetic base oil with regular mineral oil. This provides a compromise between performance and expense, while it does not attain the whole advantages of fully synthetic oils. The 40-grade guarantees that the oil retains its viscosity at elevated temperatures, averting thinning that may result in metal-on-metal contact within the engine. The 5W grade guarantees that the oil retains its fluidity at low temperatures, facilitating engine starts in cold conditions and safeguarding engine components during the crucial initial moments post-startup. Synthetic 5W40 oils are formulated to withstand oxidation and thermal degradation, thereby prolonging the oil's longevity and enhancing protection for engine components, even under rigorous use in extreme temperatures. The equilibrium of viscosity properties aids in diminishing internal engine friction, potentially enhancing fuel efficiency by reducing energy loss within the engine.

The "5W" signifies that the oil retains a reduced viscosity in low temperatures, facilitating adequate lubrication during engine ignition. This attribute is essential as cold starts are when the majority of engine wear transpires [11]. The oil rapidly reaches essential components, minimizing friction and wear during the initial seconds of operation. The "40" denotes the oil's capacity to retain its viscosity and protective layer at elevated operating temperatures. This guarantees sufficient lubrication at peak engine performance, particularly under high-load conditions or in elevated temperatures. Castrol 5W40 oil is created with modern synthetic base oils and additives intended to reduce friction among engine components. The minimal friction coefficient aids in diminishing energy loss from friction, hence enhancing engine efficiency and fuel economy. The oil sustains a robust lubricating coating even in high-stress settings, averting metal-to-metal contact. This protective coating diminishes friction, hence decreasing wear on dynamic components such as pistons, camshafts, and bearings. Castrol 5W40 incorporates anti-wear chemicals, including Zinc dialkyldithiophosphate (ZDDP), which create a protective layer on metallic surfaces. This mitigates wear, especially in high-load regions of the engine where metal contact is more probable.

The synthetic composition of the oil offers enhanced protection against abrasive and adhesive wear, guaranteeing prolonged engine longevity. The oil's capacity to preserve its protective qualities for prolonged durations renders it appropriate for contemporary engines with elevated performance requirements. Castrol 5W40 demonstrates superior thermal resilience, preserving its viscosity and lubricating characteristics even at high engine temperatures. This is essential for preventing oil degradation, oxidation, and sludge accumulation in high-performance engines that function at elevated temperatures. The oil is infused with antioxidants that inhibit oxidation, even in harsh operating conditions. This oxidation resistance prolongs the oil's protective characteristics, hence diminishing the necessity for frequent oil changes. Castrol 5W40 oil offers strong hydrodynamic lubrication, creating a thick oil layer that separates moving components, hence minimizing wear and enhancing engine performance. This is especially effective in high-velocity engine operations. In boundary lubrication circumstances, where complete fluid films fail to separate surfaces (as seen in high-pressure or low-speed operations), Castrol 5W40 provides protective additives that reduce surface-to-surface contact, thus reducing significant wear and scuffing. Castrol 5W40 exhibits robust shear stability, indicating that the oil withstands degradation or thinning under significant mechanical stress. This is particularly crucial for ensuring uniform viscosity and lubrication in high-revving engines, where oil may experience significant shearing forces [12]. The oil comprises corrosion inhibitors that safeguard engine components from rust and corrosion, particularly in conditions with fluctuating temperatures or moisture exposure. This is essential for averting long-term harm to engine components, including cylinders and valves.

Castrol 5W40 has detergents and dispersants that neutralize detrimental acids generated during combustion, hence preventing corrosion of metal surfaces within the engine.

The oil has sophisticated detergent ingredients that inhibit sludge and carbon deposit formation. This maintains engine cleanliness, guaranteeing optimal performance and extending engine longevity. Castrol 5W40 enhances fuel efficiency and diminishes emissions by minimizing sludge and carbon accumulation, rendering it an eco-friendlier lubricant. Castrol 5W40 engine oil provides superior tribological characteristics, rendering it a high-performance lubricant appropriate for many mechanical applications, especially in high-performance vehicle engines. Its low-temperature fluidity, high-temperature stability, wear resistance, and oxidation resistance provide it an optimal selection for contemporary engines functioning under diverse situations. Castrol 5W40 offers exceptional protection and efficiency in both high-speed, high-load conditions and routine driving, enhancing engine longevity and performance [13].

Sesame Oil: Refined Sesame Oil (SEO) was sourced from native oil producers and utilized without additional processing. Sesame oil has been utilized for numerous applications for ages, including as a natural lubricant [14]. It is extracted from sesame seeds and possesses characteristics that render it appropriate for lubricating in both culinary and non-culinary applications. Sesame oil is abundant in oleic acid and linoleic acid, which enhance its smooth texture and lubricating characteristics. It comprises antioxidants including sesamol and sesamin, which enhance the oil's stability and reduce its susceptibility to oxidation relative to some other natural oils [15]. It possesses moisturizing qualities that provide easy application on surfaces without obstructing pores, rendering it a flexible oil for dermatological use. Sesame oil, being a plant-based oil, is devoid of synthetic compounds and is often safe for topical application. It possesses mild anti-inflammatory and antibacterial qualities, which help alleviate irritated skin and avert infections when applied topically.

While less prevalent than mineral oils or synthetic lubricants, sesame oil is suitable for the gentle lubrication of mechanical components [16]. Its viscosity and resistance to desiccation render it appropriate for low-friction applications, including the lubrication of wooden components or basic machinery. Sesame oil possesses a relatively low to moderate viscosity, rendering it efficient in minimizing friction between moving surfaces. Viscosity may fluctuate with temperature, affecting its lubricating efficacy. Sesame oil retains steady viscosity at moderate temperatures, but its efficacy diminishes at elevated degrees due to thermal deterioration. Research indicates that sesame oil offers a low coefficient of friction, hence diminishing resistance between sliding surfaces [17]. This feature renders it appropriate for situations where minimizing friction is essential. Sesame oil demonstrates strong wear prevention properties. Its capacity to produce a layer can safeguard surfaces from deterioration and extend the longevity of components. Antioxidants in sesame oil, including sesamol and sesamin, enhance its anti-wear characteristics, preserving the integrity of lubricated surfaces over time [18]. The properties of the sesame oil are listed in Table 1 [19].

Table 1. Properties of sesame oil.

Property	Sesame oil
Density at 15 °C	923 kg/m^3
Kinematic Viscosity at 40 °C	34.97 mm^2/s
Water Content	215 mg/kg
Pour Point	-6

Olive Oil: Olive oil has been known for a long time to have many uses, one of which is as a natural lube. As a plant-based oil, it has a lot of benefits for lubrication in home and light industrial settings. The thick consistency and lubricating qualities of olive oil come from the large amount of oleic acid, a monounsaturated fatty acid, which it contains. Antioxidants, like polyphenols and vitamin E, make olive oil more stable and last longer as a lube by keeping it from oxidizing. Because it moisturizes, olive oil is great for using on your skin and to keep natural fibres like leather and wood from drying out. Because olive oil is non-toxic and completely biodegradable, it can be used in places where manufactured lubricants might be bad for the environment [20]. When massaged into the skin, olive oil can be used as a natural lube. In the past, it was used to ease dry skin and reduce friction. It's often used to grease locks, doors that squeak, and other small appliances around the house. Because it is not very toxic, it can be used in food-safe places, like kitchen tools and machines.

Olive oil can be used to protect and grease wooden surfaces, making them last longer without hurting the wood. Because olive oil doesn't have a very thick consistency, it can be used for light-duty lubrication jobs. It becomes less thick as the temperature rises, which makes it easier to work with when it's hot. When there is low speed and pressure, olive oil forms a smooth film between surfaces that cuts down on wear and friction. In a temperature of 40 °C, olive oil has a kinematic viscosity of about 36 to 40 mm^3/s. As the temperature rises, the viscosity drops, which changes how well it works as a lubricant, especially in places where the temperature changes a lot.

When there is not much weight on one side of a moving surface, olive oil has a low coefficient of friction, usually between 0.05 and 0.1. This makes moving parts work better in low-stress situations and cuts down on the energy lost through friction. Olive oil protects against mild wear by making a lubricating film that keeps the surface from wearing down. But it might not be able to fight wear well enough when there is a lot of pressure or speed. When metals are more likely to touch each other, border lubrication can help stop some wear because the fatty acids and triglycerides stick to surfaces and act as a barrier [21]. Olive oil has tribological qualities that make it useful for light mechanical uses, especially when health and environmental safety are important. In low-load and moderate-temperature settings, it reduces friction well and resists wear well. But because it breaks down at high temperatures and has a middling viscosity, it can't be used in high-load, high-speed, or high-temperature situations. So, olive oil can be used as a lubricant in some situations, but it cannot be used instead of synthetic oils or industrial lubricants in systems that need to work harder [22].

Mustard Oil: Mustard oil, derived from mustard seeds, has been long utilized in culinary practices, medicinal applications, and lubrication owing to its inherent qualities. Its potential as a lubricating oil has garnered interest for different light-duty and natural uses, presenting distinct properties in comparison to other plant-based lubricants. It comprises elevated concentrations of erucic acid (up to 40%), in addition to oleic, linoleic, and linolenic acids. These fatty acids enhance the oil's lubricating characteristics. Mustard oil possesses moderate viscosity, rendering it appropriate for minimizing friction between surfaces.

Viscosity is influenced by temperature however it stays relatively constant at mild temperatures. The oil has abundant natural antioxidants that offer resistance to oxidation and degradation nonetheless, it is less stable than certain synthetic lubricants. Consequently, it is suitable for use in domestic applications to lubricate hinges, locks, and tiny machines. Its inherent, non-toxic characteristics render it a secure choice for food-related apparatus. Mustard oil can be utilized to lubricate basic components, such as wooden mechanisms or agricultural implements, in mechanical systems characterized by low friction and mild temperature conditions [23].

Mustard oil creates a lubricating layer that minimizes direct surface contact, hence decreasing friction and wear, especially under low-stress conditions. The fatty acid composition of mustard oil offers moderate wear protection nevertheless, its efficacy decreases under high-pressure or high-speed conditions. Mustard oil possesses natural antioxidants, yet it is susceptible to oxidation at elevated temperatures, diminishing its long-term efficacy as a lubricant. Mustard oil is biodegradable and non-toxic, rendering it an environmentally sustainable choice for lubrication in contexts where synthetic oils may be detrimental to the environment. Additionally, it forms a protective coating over metal surfaces, mitigating corrosion and rusting to a degree. In comparison to synthetic lubricants, mustard oil is comparatively economical and readily available, especially in areas where mustard plants are grown. However, it possesses inherent limitations as it is prone to breakdown and oxidation at elevated temperatures, restricting its applicability in high-temperature settings [24].

Mustard oil is unsuitable for high-load applications in industrial or high-stress mechanical systems, since its lubricating coating may lack sufficient strength to mitigate wear and friction, resulting in mechanical failure. A significant issue with direct application to mechanical components is rancidity, akin to other vegetable oils, mustard oil may develop rancid over time when subjected to air, light, and heat, hence diminishing its efficacy as a lubricant. Mustard oil is suitable for lubricating small-scale agricultural implements, particularly in contexts where biodegradability is essential, such as in low-tech agriculture. Mustard oil, with its moderate viscosity and capacity to create a protective layer, is good for lubricating wooden components, including wheels, pulleys, and door hinges.

The tribological qualities, concerning friction, wear, and lubrication performance, are influenced by its chemical composition and response to mechanical stresses. Mustard oil possesses a moderate kinematic viscosity, generally ranging from 50 to 60 mm²/s (centistokes, cSt) at 40°C. This qualifies it as a medium-viscosity lubricant, appropriate for scenarios necessitating light to moderate friction reduction. The viscosity of mustard oil diminishes with rising temperature, hence impairing its lubricating efficacy at elevated temperatures. It retains efficacy in moderate temperature ranges but diminishes in reliability under excessive heat conditions. Mustard oil exhibits a comparatively low coefficient of friction owing to its fatty acid composition, particularly erucic acid, which creates a lubricating coating on surfaces. This minimizes surface-to-surface contact and decreases energy losses in low-load applications. The fatty acids in mustard oil form a stable layer on metal or other surfaces, facilitating the smooth operation of moving components, particularly under light-load or moderate-speed conditions. Mustard oil provides mild wear prevention by minimizing metal-to-metal contact via film development. Erucic acid, a monounsaturated fatty acid found in mustard oil, is integral to this protective mechanism. Under boundary lubrication circumstances, when thin oil films divide surfaces, mustard oil offers adequate protection against wear. Nevertheless, in conditions of severe pressure or heavy loads, its wear protection may be inadequate, resulting in heightened wear and tears. Mustard oil possesses considerable oxidative stability owing to its inherent antioxidant constituents, yet it is prone to oxidation when subjected to elevated temperatures for extended durations. This oxidation results in the generation of free radicals, which deteriorate the oil and diminish its lubricating efficacy [25].

Mustard oil commences degradation at temperatures exceeding 150-160°C, resulting in the formation of oxidation byproducts and a reduction in its lubricating capabilities. This renders it inappropriate for high-temperature or high-speed mechanical systems, where thermal stability is essential. Mustard oil offers a degree of corrosion prevention for metallic surfaces. The formation of a coating that isolates the surface from air and moisture aids in the prevention of rust and oxidation. Nonetheless, as time progresses, the oil deteriorates or turns rancid, resulting in a reduced capacity to prevent corrosion. Mustard oil is biodegradable and non-toxic, rendering it an eco-friendly substitute for synthetic lubricants. This feature is especially significant in contexts where soil or water contamination may pose a risk. Mustard oil is food-safe, rendering it an appropriate option for lubricating kitchen appliances, food processing equipment, and machinery where inadvertent food contact may occur. In hydrodynamic lubrication, where a substantial oil layer entirely separates moving components, mustard oil functions efficiently in low-speed, light-load scenarios. It generates an enough lubricating layer to reduce friction. Under boundary lubrication conditions, the fatty acids of mustard oil adhere to the surface, offering protection against wear. In high-pressure situations, this thin coating may deteriorate, resulting in surface damage [26].

Difference between coefficient of friction and friction factor: The COF (Coefficient of Friction) and the Friction Factor are both connected to friction in the field of tribology; however, they are utilized in different situations and reflect different notions.

Coefficient of Friction (COF): The coefficient of friction (COF) is a dimensionless quantity that expresses the ratio of the frictional force (F) that is preventing the mobility of two surfaces to the normal force (N) that is pressing them together.

COF = F/N

It is a measure that is particular to the materials and surface conditions that are involved, and it describes the ease with which one surface travels over another. There are two different kinds of COF: static COF, which refers to the resistance that precedes movement, and dynamic or kinetic COF, which refers to the resistance that occurs during movement [27].

Friction Factor (FF): The friction factor is a dimensionless quantity employed in fluid dynamics and lubrication studies, quantifying the resistance to flow within a pipe or between surfaces caused by friction. In tribology, this phrase may arise concerning lubricated surfaces, where it pertains to energy losses resulting from friction in the presence of fluid. The Darcy-Weisbach equation, applicable to flow in pipes or channels, is influenced by the Reynolds number and surface roughness. COF quantifies the frictional interaction between solid surfaces. The friction factor pertains to the resistance encountered due to friction in fluid dynamics or lubrication contexts.

2. EXPERIMENTAL DETAILS

2.1. Sample Preparation

Each of the three samples was prepared using a "Magnetic Stirrer with Hot Plate MH-2lt." Fifty grams of base engine oil (5W-40) were measured and placed in a beaker for each sample. To prepare the first sample, five grams of sesame oil, representing ten percent of the volume fraction, were added to the base oil and mixed thoroughly. Similarly, five grams of mustard oil and five grams of olive oil were mixed with the base oil to prepare the second and third samples, respectively. The mixing process was carried out meticulously to ensure uniformity and homogeneity in all the samples, which is critical for consistent testing.

2.2. Sample Testing

The tribological performance of each sample was tested using a Linear Reciprocating Tribometer (LRT) in accordance with ASTM G133 standards. The technical specifications of the LRT are detailed in Table 2, and the frequency ranges corresponding to different stroke lengths are provided in Table 3.

Table 2. Technical Specifications of LRT.

Top Specimen	Spherical Ball or Cylindrical Pin	Diameter: 4, 6, 8, 10, or 12 mm for Spherical ball
		Length: 15 mm (for cylindrical pin)
Bottom Specimen	Flat	50 x 50 x 5 mm
Normal Load	5-50 N dead weight in step of 5N	
Frequency	Up to 50 Hz	
Stroke Length	1-20 mm	
Friction Force	0-50 N	
Temperature	Ambient to 550 °C	

Table 3. Frequency Range Corresponding to Stroke Length for LRT.

Frequency	Stroke Length
1–8 Hz	20 mm
8–10 Hz	16 mm
10–20 Hz	15 mm
20–30 Hz	5 mm
30–40 Hz	2 mm
40–50 Hz	1 mm

For this study, the selected operating parameters for the tribological tests were as follows: a frequency of 20 Hz, a stroke length of 10 mm, a load of 20 N, and ambient temperature. The top specimen used was a cylindrical pin with a diameter of 8 mm and a length of 12 mm, made of EN32 material. The bottom specimen was a flat plate with dimensions of 50 x 50 x 5 mm, fabricated from High-Speed Steel (HSS). Each test was conducted for a duration of 15 minutes.

Before commencing the tests, the top and bottom specimens were thoroughly cleaned using acetone to eliminate any surface contaminants and ensure accuracy in the results. The prepared samples were then applied to the bottom specimen, ensuring even coverage across the testing surface. The Linear Reciprocating Tribometer simulated a sliding motion between the cylindrical pin and the flat HSS plate under the selected load and frequency. The tests were conducted under identical conditions for all three samples. During the tests, the friction coefficient and wear characteristics of each sample were recorded continuously. The data were collected in real-time, providing insights into the tribological behavior and performance of the different oil blends. This experimental methodology ensured reliable, reproducible results and allowed for a comparative evaluation of the additives' effects on the base engine oil's tribological properties.

3. RESULTS AND DISCUSSION

The performance of freshly manufactured blended lubricants is influenced significantly by the addition of a 10% weight fraction of various vegetable oils (sesame, olive, and mustard oil) to the base engine oil (5W-40). The tribological analysis conducted using the linear reciprocating tribometer provided insights into the coefficients of friction (COF) and friction factor (FF) of these blends compared to the base oil. The COF values for the various lubricants were as follows: sesame oil blended with engine oil (0.35), olive oil blended with engine oil (0.37), mustard oil blended with engine oil (0.38), and base engine oil (5W-40) (0.36). These findings clearly demonstrate that the sesame oil blend exhibited the lowest COF, even lower than the base oil itself. Following sesame oil, the olive oil blend demonstrated a slightly better COF than mustard oil, which had the highest COF among the blends. This indicates that sesame oil as an additive significantly enhances the lubricating properties of engine oil.

The results are visually represented in Figure 1, which compares the COF of all tested samples to the base oil. The graph highlights the superior performance of the sesame oil blend ("S+E") compared to the olive oil ("O+E") and mustard oil blends, as well as the base oil ("E").

The friction factor (FF) results further corroborate the COF findings. The FF values for the base oil, sesame oil blend, olive oil blend, and mustard oil blend were 7.24, 7.13, 7.42, and 7.68, respectively. Figure 2 illustrates the comparative FF values, where the sesame oil blend ("S+E") again outperforms the other samples, followed by olive oil ("O+E"), with mustard oil exhibiting the highest FF.

The superior tribological performance of sesame oil when blended with base engine oil (5W-40) can be attributed to its intrinsic physicochemical properties. Sesame oil likely forms a more stable and resilient lubricating film under the test conditions, reducing metal-to-metal contact and minimizing friction. This phenomenon can be linked to the molecular composition and viscosity of sesame oil, which play a crucial role in its friction-reducing capabilities.

The slightly higher COF and FF values observed for olive oil and mustard oil blends suggest that while these oils offer some friction-reducing benefits, their tribological properties are not as optimized as sesame oil. The differences in performance could be due to variations in viscosity, fatty acid composition, and the ability of each oil to form a stable lubricating film. It is worth noting that these results are specific to the 10% blending ratio used in this study. Adjusting the blending percentages may yield different results and warrants further investigation.

The significant reduction in COF and FF with sesame oil as an additive implies potential improvements in energy efficiency and durability of mechanical components. Reduced friction translates to lower energy losses, which is particularly valuable in applications demanding consistent performance. Additionally, the lower frictional forces can help minimize wear and tear on contacting surfaces, thereby extending the lifespan of mechanical components.

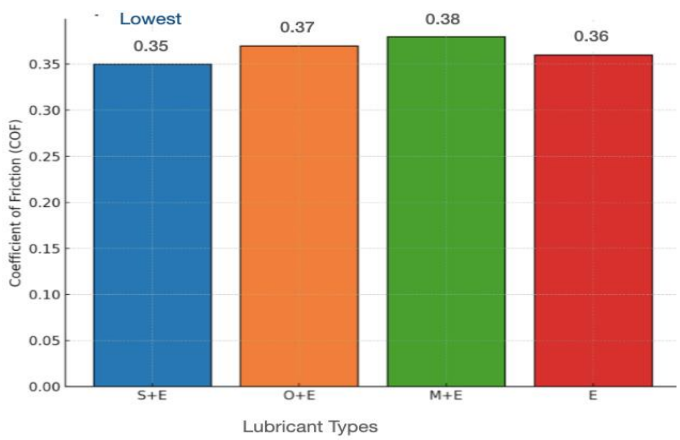

Fig. 1. Comparison of Coefficient of Friction for Different Lubricant.

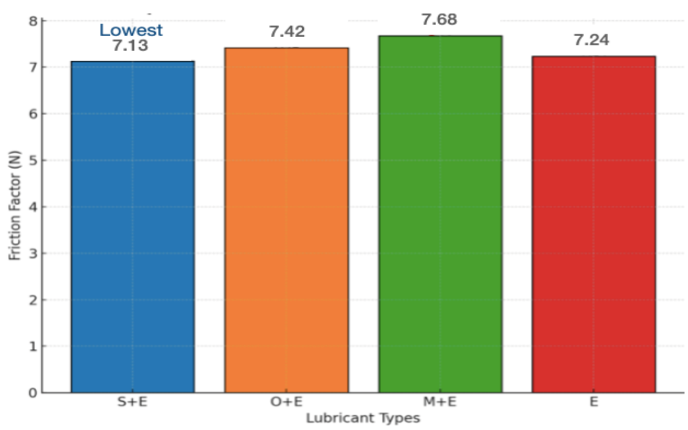

Fig. 2. Comparison of Coefficient of Friction Factor for Different Lubricant.

Oxidative stability is a critical factor influencing the performance and longevity of lubricants. Sesame oil's natural antioxidant compounds, such as sesamol and sesamin, contribute to its resistance to oxidative degradation. This characteristic likely enhances the oil's ability to maintain its lubricating properties over extended periods, especially under the high-pressure and high-temperature conditions simulated during testing. In comparison, olive oil and mustard oil may lack the same level of oxidative stability, which could affect their long-term performance.

Viscosity plays a pivotal role in determining a lubricant's ability to form a protective film between contacting surfaces. Sesame oil's favorable viscosity characteristics likely contributed to its superior performance in terms of COF and FF. The stable film formation reduces direct surface contact, resulting in lower frictional forces. Olive oil and mustard oil, with slightly different viscosity profiles, may not have provided the same level of film strength, leading to their comparatively higher COF and FF values.

While this study highlights the potential of sesame oil as an effective lubricant additive, it is important to recognize its limitations. The research was conducted using a fixed blending ratio (10%) and under specific test conditions, including ambient temperature and a constant load of 20 N. Future studies should explore the effects of varying blending ratios, temperatures, and loads to optimize the performance of vegetable oil-based additives. Additionally, the long-term stability and performance of these blends under real-world operating conditions need to be evaluated. Furthermore, while sesame oil showed promising results, the economic and environmental implications of large-scale adoption should be considered. Investigating the sustainability and cost-effectiveness of vegetable oil-based lubricants could pave the way for their broader application in industrial and automotive sectors.

The addition of sesame oil as an additive to base engine oil (5W-40) demonstrates significant potential for improving lubricity and reducing friction. The results indicate that sesame oil outperforms olive oil and mustard oil in terms of both COF and FF, making it a highly effective lubricant additive. This study lays the foundation for further exploration into sustainable and efficient lubricant formulations using vegetable oils. Future research should focus on optimizing blending ratios, testing under diverse conditions, and assessing the long-term stability and performance of these additives. By leveraging the unique properties of sesame oil, it is possible to develop environmentally friendly lubricants that enhance energy efficiency and extend the lifespan of mechanical components.

4. CONCLUSION

This study explored the tribological properties of engine oil (5W-40) blended with natural vegetable oils—sesame oil, mustard oil, and olive oil—used as friction-reducing additives in a 10% volume proportion. The primary aim was to evaluate their effectiveness in improving the coefficient of friction (COF) and friction factor (FF) of the base oil. Samples were prepared using a magnetic stirrer and analyzed using a Linear Reciprocating Tribometer (LRT). The results revealed that blending vegetable oils significantly alters the tribological performance of the base oil. Sesame oil demonstrated superior friction-reducing capabilities, with the lowest COF (0.35) and FF (7.13), outperforming the base oil, which exhibited a COF of 0.36 and FF of 7.24. This performance can be attributed to sesame oil's chemical composition, enabling improved boundary lubrication and uniform film formation. Olive oil also showed moderate effectiveness, with a COF of 0.37 and FF of 7.42, indicating potential as a viable additive. Mustard oil, however, provided the least improvement, with the highest COF (0.38) and FF (7.68) among the tested blends. The hierarchical performance of these additives—sesame oil being the most effective, followed by olive oil and mustard oil—emphasizes the role of fatty acid composition and viscosity in determining friction-reducing properties. Incorporating sesame oil into engine oil could lead to enhanced fuel efficiency, reduced wear, and extended engine component lifespan. Future research should focus on understanding the underlying mechanisms driving these friction-reducing properties, optimizing additive concentrations, and assessing the long-term stability and performance of these natural additives under varied operational conditions. Additionally, investigating their oxidative resistance and scalability for industrial applications could pave the way for broader adoption in sustainable lubrication systems.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests.

REFERENCES

[1] Wilson, B., **1998.** Lubricants and functional fluids from renewable sources. *Industrial Lubrication and Tribology*, *50*(1), pp.6-15.

[2] Li, F., Hanson, M.V. and Larock, R.C., **2001.** Soybean oil–divinylbenzene thermosetting polymers: synthesis, structure, properties and their relationships. *Polymer*, *42*(4), pp.1567-1579.

[3] Holmberg, K. and Erdemir, A., **2017.** Influence of tribology on global energy consumption, costs and emissions. *Friction*, *5*, pp.263-284.

[4] Taylor, R.I., Dixon, R.T., Wayne, F.D. and Gunsel, S., **2005.** Lubricants & energy efficiency: life-cycle analysis. In *Tribology and Interface Engineering Series* (Vol. 48, pp. 565-572). Elsevier.

[5] Holmberg, K. and Erdemir, A., **2017.** Influence of tribology on global energy consumption, costs and emissions. *Friction*, *5*, pp.263-284.

[6] Manu, B.R., Gupta, A. and Jayatissa, A.H., **2021.** Tribological properties of 2D materials and composites—a review of recent advances. *Materials*, *14*(7), p.1630.

[7] Berman, D., Erdemir, A. and Sumant, A.V., **2014.** Graphene: a new emerging lubricant. *Materials today*, *17*(1), pp.31-42.

[8] Mosey, N.J., Muser, M.H. and Woo, T.K., **2005.** Molecular mechanisms for the functionality of lubricant additives. *Science*, *307*(5715), pp.1612-1615.

[9] Kreivaitis, R. and Andriušis, A., **2018.** Comparison of tribological properties of sae 0W-40 and 5W-40 diesel engine oils. *Agricultural Engineering*, *50*(1), pp.1-7.

[10] Cerny, J., Strnad, Z. and Sebor, G., **2001.** Composition and oxidation stability of SAE 15W-40 engine oils. *Tribology International*, *34*(2), pp.127-134.

[11] Keller, J., Fridrici, V., Kapsa, P., Vidaller, S. and Huard, J.F., **2008.** Influence of material nature and surface texturing on wear of heavy-duty diesel engine cylinder liners. *Tribology Transactions*, *52*(1), pp.121-126.

[12] Kaleli, H., Demirtaş, S., Uysal, V., Karnis, I., Stylianakis, M.M., Anastasiadis, S.H. and Kim, D.E., **2021.** Tribological performance investigation of a commercial engine oil incorporating reduced graphene oxide as additive. *Nanomaterials*, *11*(2), p.386.

[13] Schiemen, R.D., **1983.** *Extended service 5w-40 motor oil* (No. US 4402841).

[14] Anilakumar, K.R., Pal, A., Khanum, F. and Bawa, A.S., **2010.** Nutritional, medicinal and industrial uses of sesame (Sesamum indicum L.) seeds-an overview. *Agriculturae Conspectus Scientificus*, *75*(4), pp.159-168.

[15] Lammari, N., Louaer, O., Meniai, A.H., Fessi, H. and Elaissari, A., **2021.** Plant oils: From chemical composition to encapsulated form use. *International Journal of Pharmaceutics*, *601*, p.120538.

[16] Sabarinath, S., Rajendrakumar, P.K. and Prabhakaran Nair, K., **2019**. Evaluation of tribological properties of sesame oil as biolubricant with SiO2 nanoparticles and imidazolium-based ionic liquid as hybrid additives. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, *233*(9), pp.1306-1317.

[17] Oboulbiga, E.B., Douamba, Z., Compaoré-Sérémé, D., Semporé, J.N., Dabo, R., Semde, Z., Tapsoba, F.W.B., Hama-Ba, F., Songré-Ouattara, L.T., Parkouda, C. and Dicko, M.H., **2023.** Physicochemical, potential nutritional, antioxidant and health properties of sesame seed oil: a review. *Frontiers in Nutrition*, *10*, p.1127926.

[18] Sankaran Nair, S., Prabhakaran Nair, K. and Rajendrakumar, P.K., **2018.** Micro and nanoparticles blended sesame oil bio-lubricant: study of its tribological and rheological properties. *Micro & Nano Letters*, *13*(12), pp.1743-1746.

[19] Arumugam, S., Sriram, G. and Subadhra, L., **2012.** Synthesis, chemical modification and tribological evaluation of plant oil as bio-degradable low temperature lubricant. *Procedia Engineering*, *38*, pp.1508-1517.

[20] Calomir, C., Stefanescu, I., Solea, L. and Chirita, G., **2008.** Vegetal oils as lubricating materials. *Tribology*, *14*, pp.154-160.

[21] Liu, J., Zhang, R., Yang, S., Liu, T., Yi, C., Zhang, Y. and Jia, D., **2023.** Evaluation of Anti-wear Properties of Different Vegetable Oils Based on QSPR Model. *Tribology Letters*, *71*(2), p.35.

[22] Charoo, M.S., Akhter, F., Hanief, M., Wani, K.S. and Nissar, M., **2023.** Effect of saturated fatty acids on the antiwear and rheological properties of olive oil. *Tribology in Industry*, *44*(1), p.121.

[23] Zuan, A.M.S., Syahrullail, S., Arif, M.D. and Kamitani, S., **2017.** Tribological performance of palm kernel oil at various load using pin-on-disk tribotester. *Journal of Mechanical Engineering*, *1*, pp.91-102.

[24] Jabal, M.H. and Khalefa, M.Z., **2018.** Tribological characteristics evaluation of mustard oil blends. *Journal of Engineering*, *24*(3), pp.1-12.

[25] Hussain, A., Mehdi, S., Ali, A., Adeel, M., Jabal, M. and Ani, F., **2018**. Investigation of tribological characteristics of castor oil with mineral oil blends. *Journal of Engineering and Applied Sciences*, *37*(1), p.6.

[26] Abdel Hamid, E.M., Amer, A.M., Mahmoud, A.K., Mokbl, E.M., Hassan, M.A., Abdel-Monaim, M.O., Amin, R.H. and Tharwat, K.M., **2024**. Box-Behnken design (BBD) for optimization and simulation of biolubricant production from biomass using aspen plus with techno-economic analysis. *Scientific Reports*, *14*(1), p.21769.

[27] Ojaomo, K.E., Syahrullail, S., Zawawi, F.M. and Yusop, M.Z., **2023.** Potential of palm oil with tert-Butylhydroquinone in place of mineral oil lubricant for reducing environmental degradation. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, *237*(6), pp.1342-1352.

