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STUDY OF FRICTION AND WEAR CHARACTERISTICS OF AISI 1055 WITH MODIFIED NEEM OIL AS ENGINE LUBRICANT IN FOUR-STROKE SI ENGINES

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Abstract

This paper explores the use of neem oil as a lubricant for petrol engines. Raw neem oil undergoes a two-step esterification process to produce Neem Trimethylolpropane Ester (NTMPE). The engine used for testing is an air-cooled, four-stroke, single-cylinder petrol engine with a power output of 1.3 kW at 4200 rpm. Various blends of mineral oil (petroleum oil) and NTMPE are employed as lubricants during the trials. The engine is tested under varying loads, and the performance and emissions of these blends are compared to those achieved with mineral oil. The results indicate that using the NTMPE 20–MO 80 blend, instead of mineral oil, leads to a 10% reduction in fuel consumption, a 9% increase in thermal efficiency, and a slight improvement in mechanical efficiency. Additionally, the engine running on the NTMPE 20–MO 80 blend produces approximately 10% less carbon monoxide and an 8% reduction in unburnt hydrocarbons concentration compared to when using a petroleum-based lubricant. Tribological tests on NTMPE 20–MO 80 are conducted using a pin-on-disc tribometer with AISI 1055 carbon steel. The friction and wear behavior with modified vegetable oil lubrication are compared to results obtained with mineral oil. Additionally, images of the worn pin surfaces are captured using a scanning electron microscope (SEM). SEM surface analysis shows that NTMPE provides better lubrication than mineral oil (SAE 20W40), leading to an approximate 8% reduction in the friction coefficient

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and a 5% decrease in wear. The study was a low power engine. In order to ascertain the variability of Neem Trimethylolpropane Ester (NTMPE), more study should be conducted using a typical engine, e.g. a car engine.

Keywords: neem oil; mineral oil; biolubricant; trimethylolpropane; esterification

1. Introduction

Petroleum-based lubricants are dangerous, biodegradable to a limited extent, and a major source of pollution in the environment. Alternative lubricants made from non-edible vegetable oils are becoming more and more necessary for industrial and automotive use as environmental concerns grow [1]. Long fatty acid chains and polar groups characterise vegetable oils, also referred to as triglycerides of fatty acids. These synthetic vegetable oils, known as biolubricants, can take the place of mineral oils due to their inherent technical properties and capacity to biodegrade following a two-step esterification process. When compared to mineral oils, vegetable oil-based biolubricants frequently have higher viscosity indices, flash points, fewer evaporative losses, and lower toxicity [2, 3]. Through the formation of a stable layer between surfaces, long fatty acid chains can lessen wear and friction. They work well as hydrodynamic and boundary lubricants as well. They do, however, have certain drawbacks, like reduced oxidative and thermal stability [4]. High oleic vegetable oils are a good substitute for conventional lubricants made of mineral oils and synthetic esters due to their improved oxidative stability [5]. Several studies suggest that low temperature fluidity and poor thermo-oxidative firmness in vegetable oils can be effectively addressed through chemical modifications and additive integration [6]. These articles explore recent advancements in the use of chemical formulation processes, such as transesterification, epoxidation, and estolide synthesis, to create biolubricants from vegetable oils. It has been demonstrated that these methods greatly improve the physical characteristics of the base vegetable oils, producing biolubricants that meet or exceed performance standards [7, 8]. SAE-40 lubricant samples contaminated with known gasoline percentages have been studied by researchers. They create fuels using B30, a combination of diesel palm-sesame biodiesel. They combined B30 with carbon nanotubes, titanium oxide, ethanol, and dimethyl carbonate. Then used a 4-ball tribotester to determine how different fuels affected the lubricant's tribological properties, and then looked into the SEM of worn surfaces to determine the forms of wear. The findings demonstrate that, in contrast to conventional diesel and alcoholic fuel additives, biodiesel blends (B30) with nanoparticles slow down lubricant degradation [9].

Using HFRR and a four-ball tribometer, the authors investigated the tribological performance of cottonseed oil added to SAE 40. The lowest COF and wear in relation to SAE 40 are seen when 10% cottonseed biolubricant is added. However, friction and wear also increase when the volume percentage of cottonseed oil in SAE 40 rises above 10%. In order to reduce partial dependency on commercial mineral oil, 10% TMP cottonseed oil can be added as a lubricant additive [10].

Using a calcium hydroxide catalyst, sesame methyl ester was chemically transesterified with trimethylolpropane (TMP) to form polyol ester, a novel biodegradable base stock made from sesame seed oil for the production of lubricants. The results showed that the sesame biolubricant had viscosities of 35.55 cSt at 40°C and 7.66 cSt at 100°C. In addition, the viscosity index, pour point, and flash point were found to be 193°C, −21°C, and 196°C, respectively [11]. The tribological performance of JME-based bio-lubricants has been examined by the authors through testing of severe pressure and anti-wear characteristics. They used a four-ball tribotester to conduct their experiments in accordance with ASTM D 2783 and ASTM D 4172 standards, respectively. They then contrasted the SAE 15W-40 lubricant's properties with those of bio-lubricants based on JME. After conducting research, they determined that 10% JME bio-lubricant (BL10) was the best option because it satisfies all standard ISO requirements without requiring a pour point [12]. To propose alternate sources for tribological uses, the authors have conducted experiments on neem oil. SiO_2 nanoparticles were employed to enhance the oil's lubricating qualities. They used a DUCOM tribometer to do experiments at various loads. The lowest COF was achieved when 0.3% nanoparticles were introduced. However, disc wear also increased as more nanoparticles were introduced. In comparison to raw neem oil, experimental results indicated that adding 0.3% of nanoparticles improved its tribological qualities [13]. To boost the oil's lubricating qualities, the authors added TiO_2 nanoparticles. Using a DUCOM tribometer, they conducted experiments at different loads while maintaining a constant temperature. They introduced nanoparticles in different concentrations in accordance with earlier studies. The use of nanoparticles resulted in a minimal COF of up to 0.3%. However, disc wear increased when more nanoparticles were introduced. In comparison to raw jojoba oil, experimental results indicated that adding 0.3% of nanoparticles improved its tribological qualities [14]. The authors assessed exhaust emissions using a single-cylinder, four-stroke diesel engine and examined sunflower oil using a four-ball tribometer to comprehend its lubricating properties at different loads. At low loads, sunflower oil outperformed petroleum oil in terms of tribological properties. According to experimental data, SO-based lubricant outperformed other lubricants in reducing exhaust gas emissions under different test settings. Thus, the potential of SO-based lubricant to be applied as a lubricant at contacting surfaces is demonstrated [15]. Authors combined waste cooking oil (WCO) and lubricating oil to produce biodiesel because of cost-effective sources. With the use of an HFRR & POD tester, they investigated the tribological properties of the cam-tappet and piston-cylinder liner in the valve train under wet lubrication conditions. They also use the analytical ferrography method to examine wear particles found in the lubricants. The results indicate that COF and WSD performed better when 10% WCO biodiesel was combined with SAE20W40 [16]. With the use of a ball-on-flat reciprocating machine, the authors have examined the tribological performance of Jatropha oil at different frequencies. For all tests, they used a 12 N load and monitored COF for 40 minutes while using AISI 52100 steel and X210Cr12 as contacting surfaces. They also examined the chemical and physical characteristics of Jatropha oil. They draw the conclusion from the data that COF falls with increasing frequency, with the final value falling between 0.04 and 0.122 [17]. The thermal-oxidative stability of palm oil containing phenolic antioxidants has been tested by the authors, and the outcomes are contrasted with those of superior mineral engine oil. According to studies, a consistent combination of palm and tertiary-butyl hydroquinone produced respectable antioxidant qualities. Additionally, this mixture lessens friction and wear [18]. The author has conducted experiments to examine the tribological characteristics of the Al-7% Si alloy when lubricant oil is combined with Jatropha oil. This study demonstrates that the base lubricant's performance and anti-wear properties improved when 15% Jatropha oil was added [19]. The authors looked at the tribological properties of lubricating oil that had boron nitride added to it. Using a rheometer and a tribo-tester, they examine the lubricating oil's rheological action as well as its anti-frictional and anti-wear properties. They come to the conclusion that lubricating oil works best when boron nitride additives are applied in small amounts [20]. Biolubricants derived from the fatty acids of castor oil were produced through esterification (over 93 wt.%), epoxidation (over 92 wt.%), and oxirane ring opening reactions utilizing water (over 92 wt.%) or 2-ethylhexanol (over 94 wt.%) as nucleophiles were studied. The frictional properties of the synthesized biolubricants were evaluated using tribological tests conducted with a four-ball tester, and the results were compared to those of a commercial mineral oil. Notably, the sample produced via oxirane ring opening with water exhibited the most favourable frictional characteristics among all samples tested, demonstrating an equivalent wear rate and approximately 20% lower friction coefficient compared to the commercial mineral oil, highlighting its significant potential as a substitute for mineral fossil oils [21].

This study looks at lubricating a four-stroke petrol engine with biolubricant derived from neem oil. Blends of modified neem oil and conventional petroleum oil were used to lubricate the engine; the results were compared with traditional mineral oil to assess the engine's performance and emissions. The study also compares the tribological behaviour of modified neem oil with standard lubricants and looks at the tribological properties of the oil meant for use in automobile engines.

2. Structural Modification of Neem Oil

Raw vegetable oil, while recognized as a renewable and environmentally friendly resource, is not suitable for direct application as an engine lubricant due to several significant limitations that affect its performance and longevity. One of the main concerns is its insufficient viscosity, as vegetable oils do not possess the necessary thickness to create an effective protective film between moving engine components, which can result in increased wear and friction. Furthermore, these oils exhibit poor thermal stability, leading to degradation at the high temperatures typically encountered during engine operation, thereby diminishing their lifespan and efficiency. Another major issue is their high oxidation rate; raw vegetable oils are susceptible to reacting with oxygen, which can produce sludge and acids that may harm engine parts. Their low lubricity, or ability to minimize friction, further restricts their performance when compared to traditional lubricants. The lack of critical additives, such as anti-wear agents and corrosion inhibitors, renders them inadequate for the requirements of modern engines. Additionally, raw vegetable oils perform poorly in cold temperatures, often becoming excessively thick or solidifying, which hinders their effectiveness in colder climates. The propensity for gumming and deposit formation is another serious concern, as these residues can obstruct engine components, leading to reduced efficiency and increased maintenance needs. Although their biodegradability is an ecological benefit, it can also result in premature degradation under engine conditions, particularly when exposed to contaminants like water or dirt. To overcome these challenges, extensive research indicates that chemical modification of vegetable oils is necessary. Methods such as transesterification, epoxidation, and hydrogenation are utilized to improve characteristics like viscosity, thermal stability, and oxidation resistance. Additionally, the incorporation of appropriate additives into these enhanced oils significantly boosts their performance, rendering them effective as engine lubricants. These innovations confirm that vegetable oil-based lubricants can serve as sustainable and high-performance alternatives to petroleum-derived products, supporting both environmental and technological objectives. The fatty acid composition of neem oil after testing is shown in Table 1.

Tab. 1. Fatty acid makeup of neem oil [22]

Fatty acid	Neem oil (%)
Linoleic acid	40
Oleic acid	35
Cis-13-octadecenoic acid	8.9
Palmitic acid	8.5
Stearic acid	7.5
Cis-vaccenic acid	0.5

The ester form of neem oil known as NEPO is produced during the first stage of oil synthesis when neem oil is transesterified with methanol. In order to create the ester of Neem Trimethylolpropane (NTMPE), also referred to as modified Neem oil for experimental research, this Neem methyl ester is subjected to a second transesterification using Trimethylolpropane (TMP) in the subsequent stage. Table 2 displays the physicochemical properties of both mineral oil (petroleum oil) and modified Neem oil.

Tab. 2. Physical-chemical characteristics of mineral oil and modified Neem oil (NTMPE) [23]

Characteristics	NTMPE	Engine oil (SAE 20W40)
Kinematic Viscosity, (mm^2/s)		
40°C	12.34	19.26
100°C	4.46	1.28
Viscosity Index	240.73	123
Fire point (°C)	124	208
Flash point (°C)	126	200

3. Engine performance, emission and tribological study

For experimental evaluations of engine performance and fuel properties, a single-cylinder, air-cooled, four-stroke petrol engine is utilized. This engine can produce a maximum power output of 1.3 kW at a speed of 4200 rpm, making it ideal for controlled and accurate testing environments. Its single-cylinder configuration promotes ease of construction and operation, allowing for a concentrated assessment of factors such as fuel efficiency, emissions, and thermal performance. To facilitate precise measurement and analysis of the engine's performance across various testing conditions, it is fitted with an electric dynamometer. This dynamometer plays a vital role by enabling precise control of the engine load and facilitating the measurement of key performance metrics, including power output, torque, and fuel consumption. Furthermore, it allows for real-time observation of the engine's operational characteristics at different speeds and loads, ensuring thorough data collection for experimental evaluation. Figure 1 depicts the experimental setup that was used for these tests.

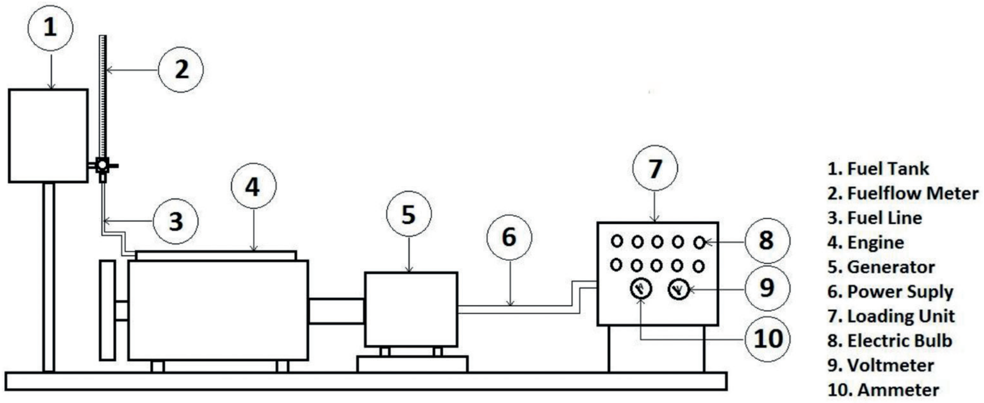

Fig.1. Experimental arrangement

Some of the volume ratios in which NTMPE and mineral oil are blended are 10% NTMPE and 90% mineral oil (NTMPE10–MO90), 20% NTMPE and 80% mineral oil (NTMPE20–MO80), 30% NTMPE and 70% mineral oil (NTMPE30–MO70), 40% NTMPE and 60% mineral oil (NTMPE40–MO60), and 50% NTMPE and 50% mineral oil (NTMPE50–MO50). Engine parameters such particular fuel consumption, mechanical efficiency, and brake thermal efficiency are calculated. Carbon monoxide and hydrocarbons are two more emission components that are measured using a flue gas analyser.

For tribological investigations, a pin-on-disc tribotester was employed as shown in Figure 2. The specimens used were spherical pins, each measuring 10 mm in diameter and 30 mm in length. A load of 75 N, a disc speed of 200 rpm, a track diameter of 100 mm, and a 30-minute test period were the parameters. AISI 1055 was lubricated with mineral oil for the duration of the wear and friction tests. Furthermore, a second series of experiments was carried out with a lubricant that was modified neem vegetable oil. An analysis was conducted with a scanning electron microscope on the worn surfaces of the pins.

Fig. 2. Pin-on-disc tribometer

The pin-on-disc tribometer is utilized to assess the tribological characteristics, including wear and friction, of materials in a controlled environment. In these evaluations, the test specimen is composed of carbon steel with an AISI 1055 grade, which is a medium-carbon steel recognized for its optimal combination of strength, hardness, and wear resistance. AISI 1055 steel typically contains around 0.50–0.60% carbon, along with trace amounts of manganese, silicon, and other elements that enhance its mechanical properties. This material is widely employed in the manufacturing of various automotive components due to its superior machinability, moderate toughness, and resilience under high-stress conditions. Notable automotive parts made from AISI 1055 carbon steel include tappets, gears, valves, camshafts, and cam lobes. The application of AISI 1055 steel in these components underscores its appropriateness for situations where strength, wear resistance, and durability are critical. Table 3 shows chemical composition of AISI 1055 Carbon steel.

Tab. 3. AISI 1055 Carbon steel's chemical arrangement [24]

Element	Percentage of content (mass %)
Carbon, C	0.55
Manganese, Mn	0.75
Iron, Fe	98.65
Sulphur, S	0.035
Phosphorous, P	0.02
Molybdenum, Mo	0.05
Silicon, Si	0.2

4. Results and Discussion

The relationship between mechanical efficiency and brake power for different mineral oil and NTMPE combinations is shown in Figure 3. The findings suggest that the mechanical efficiency of the engine is improved by mixing NTMPE with mineral oil. The equation used to find mechanical efficiency is:

$$\eta_{mech} = \frac{Brake\ Power}{Indicated\ Power} * 100$$

Compared to pure mineral oil lubrication, the mechanical efficiency significantly increases under NTMPE10–MO90 and NTMPE20–MO80 lubrication modes at high load. However, the mechanical efficiency is lower than that of mineral oil for blends of NTMPE30–MO70, NTMPE40–MO60, and NTMPE50–MO50, with the NTMPE50–MO50 blend having the lowest efficiency. The oleic acid content in the fatty acid composition may be the cause of the increase in mechanical efficiency in blends with NTMPE10–MO90 and NTMPE20–MO80 lubrication modes. Also, the structural features of vegetable oils, including their long fatty acid chains and polar functional groups, significantly contribute to their effectiveness in both boundary and hydrodynamic lubrication scenarios. These attributes enable vegetable oils to serve as highly efficient lubricants across a variety of tribological applications, providing an excellent balance of load-carrying capacity, minimized friction, and enhanced wear protection across diverse operational environments [1–3]. The long hydrocarbon segments of the fatty acid chains are crucial for improving lubrication properties, as they facilitate the formation of a stable lubricating film between interacting surfaces. The extended length of these chains promotes increased molecular entanglement, which raises the oil's viscosity and helps sustain an effective lubricating layer under moderate loads. This ability to establish a cohesive and thick boundary layer is vital for preventing direct contact between metal surfaces during operation, thereby reducing friction and wear. Such properties are especially important in boundary lubrication situations, where the lubricant film is thinner and the risk of metal-to-metal contact is heightened [4, 5].

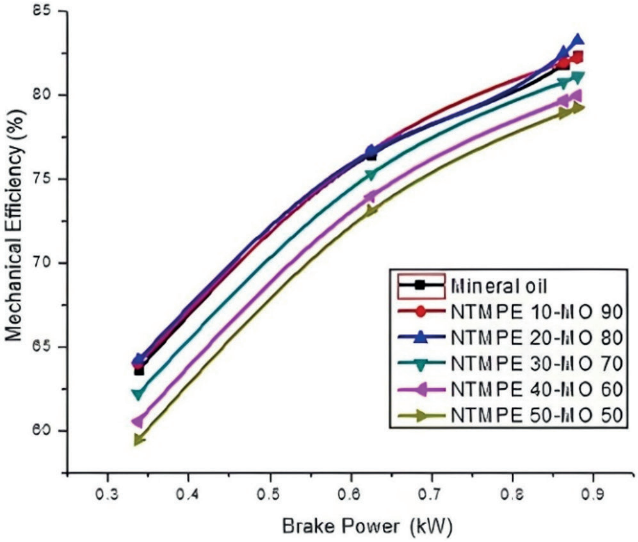

Fig. 3. Brake power and mechanical efficiency variations

The relationship between brake power and brake thermal efficiency for various mineral oil and PTMPE combinations is shown in Figure 4. The equation used to find brake thermal efficiency is:

$$\eta_{brake} = \frac{Brake\ power}{mass\ flow\ rate\ of\ the\ fuel * Calorific\ value\ of\ the\ fuel} * 100$$

The findings demonstrate that the blend NTMPE20-MO80 exhibits a roughly 10% increase in brake thermal efficiency at full load, most likely as a result of the blend's matching gain in mechanical efficiency. Neem oil is characterized by its natural lubricating properties, primarily attributed to its high oleic acid content, which minimizes friction among engine components. This friction reduction results in lower mechanical losses, thereby enhancing the overall efficiency of the engine. The excellent lubricating characteristics of neem oil facilitate better sealing within the combustion chamber, leading to more effective combustion processes. This improved combustion contributes to the engine's thermal efficiency. Neem oil-based biolubricants demonstrate commendable thermal stability and oxidation resistance, ensuring reliable lubrication performance even under elevated temperature conditions, which is essential for sustaining engine efficiency during peak loads. Additionally, the viscosity of neem oil blends can be fine-tuned to maintain a stable lubricating film between moving parts, effectively reducing energy losses from fluid friction and enhancing brake thermal efficiency. With the other blends, the engine efficiency does, however, somewhat decline. The NTMPE50-MO50 lubrication mode exhibits the lowest thermal efficiency.

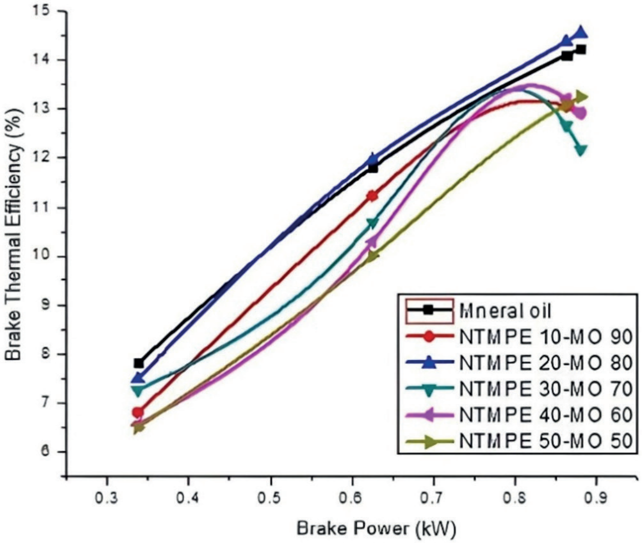

Fig. 4. Brake power and brake thermal efficiency fluctuations

The variation in specific fuel consumption with brake power for various mineral oil and NTMPE combinations is shown in Figure 5. According to the results, the blend NTMPE20-MO80 uses the least fuel when operating at full load roughly 10% less than when using pure mineral oil lubrication. The unique composition of its fatty acids improves boundary lubrication characteristics, leading to decreased friction and wear in the engine. This decrease in friction results in lower energy losses, facilitating a more efficient transformation of fuel energy into mechanical work. Additionally, it possesses a superior viscosity index compared to mineral oil, which provides enhanced film strength across a range of temperatures. This attribute ensures optimal lubrication under various operating conditions, thereby improving engine efficiency and contributing to lower fuel consumption.

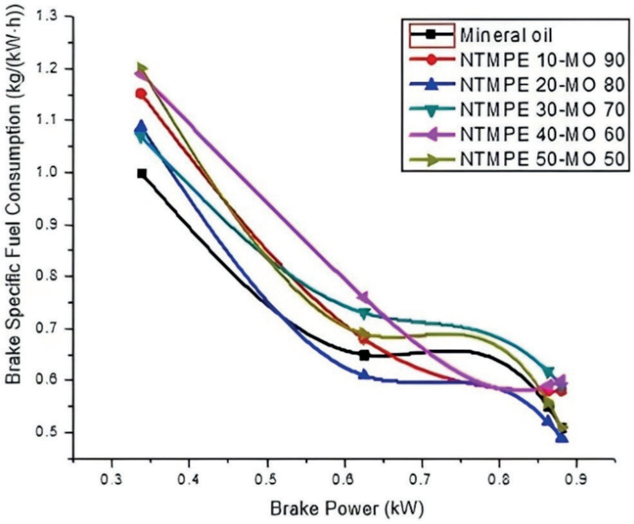

Fig. 5. Variation in a Brake specific fuel consumption with braking force

The fluctuation in carbon monoxide concentration with brake power for various mineral oil and NTMPE blends is displayed in Figure 6. Emissions for the NTMPE20–MO80 blend were examined in particular because of its better engine performance. According to the research, the NTMPE20–MO80 blend lubricates with pure mineral oil while reducing carbon monoxide concentration by about 10%. This reduction is most likely the result of superior combustion characteristics brought about by increased mechanical efficiency, improved thermal efficiency, and decreased fuel consumption, as well as the blend's higher flash point and lower volatility.

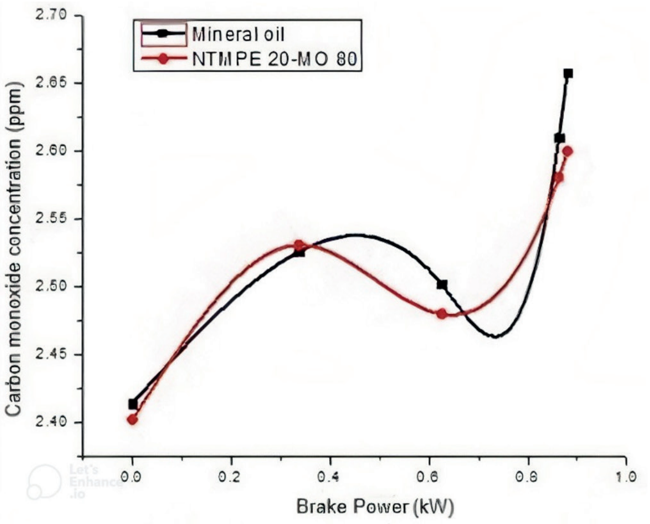

Fig. 6. Carbon monoxide fluctuation in relation to braking power.

The fluctuation in unburned hydrocarbon concentration for the NTMPE and mineral oil blend with brake power is shown in Figure 7. The findings indicate that as compared to pure mineral oil lubrication, the NTMPE20–MO80 blend minimises unburned hydrocarbon concentration by about 8% at full load. Enhanced combustion efficiency at partial load conditions may be attributed to the improved lubricating properties of the modified oil, which contribute to the engine's mechanical efficiency. The reduction in friction and wear facilitated by the modified oil can improve sealing within the combustion chamber and optimize energy transfer, leading to more thorough combustion and decreased hydrocarbon concentration.

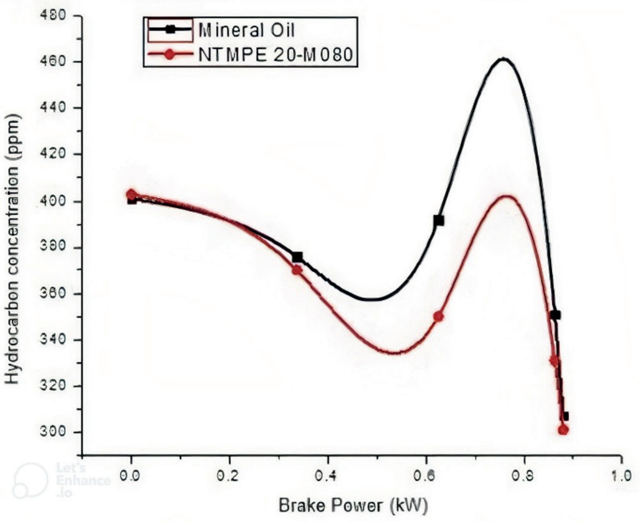

Fig. 7. Fluctuation of hydrocarbon with brake power

The decreased levels of unburned hydrocarbons and carbon monoxide could be explained by the bio-lubricant's increased viscosity when compared to mineral oil. Because of the greater viscosity, there is less engine friction, which allows for more air intake and improves the engine's volumetric efficiency. The reduction in emission concentration when using bio-lubricant instead of mineral oil is probably due to the combustion chamber having enough oxygen to burn the fuel more thoroughly.

Figure 8 illustrates how the friction coefficient varies with sliding distance when mineral oil (SAE 20W40) is used to lubricate NTMPE20-MO80 blend. When NTMPE20-MO80 is used in place of mineral oil, the friction coefficient decreases by around 8%, making it more friction-efficient than petroleum oil. The higher oxidation stability of modified vegetable oils especially as a result of the transesterification of methyl esters and trimethylolpropane from vegetable sources is responsible for this decrease in friction. The study's oils were altered to drastically lower wear characteristics and friction.

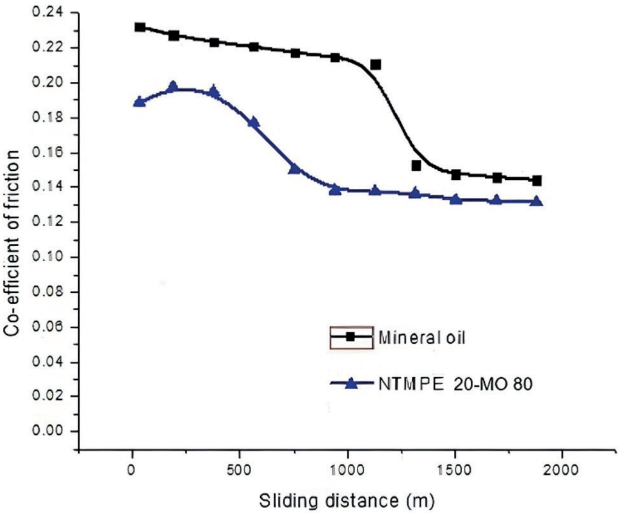

Fig. 8. Variation in the friction coefficient for various lubricants with sliding distance

The variation in wear with sliding distance when lubricating Neem Trimethylolpropane Ester (NTMPE20–MO80) blend with mineral oil (SAE 20W40) is shown in Figure 9. The findings show that, in comparison to conventional oil, wear is reduced when using modified vegetable oil for lubrication. Wear on NTMPE20–MO80 decreases over the course of the operating period; when NTMPE20–MO80 is used in place of mineral oil, wear is lowered by around 5%. The reason for this decrease is because modified vegetable oils contain polar functional groups that increase wear resistance by improving lateral contact between ester chains and increasing adsorption on metal surfaces. Direct contact between the rubbing surfaces is prevented by this molecular interaction, which creates a barrier. Chemically modified vegetable oils are more effective than mineral oils because of their strong polarity, which is enhanced by ester linkages.

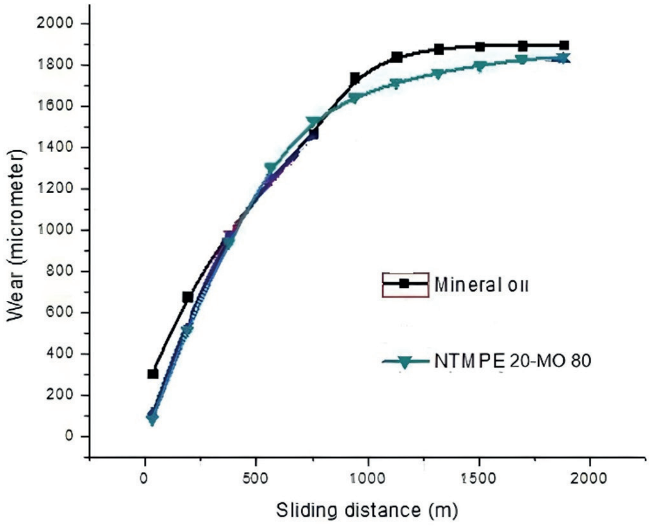

Fig. 9. Fluctuation in wear with sliding distance for different lubricants

5. Analysis of Scanning Electron Microscope (SEM)

The metal surface undergoes significant abrasion during sliding motion due to metal-to-metal contact. Analyzing the properties of the worn surfaces offers valuable insights into the interactions between metal and additives, as well as the effectiveness of vegetable oil as a boundary lubricant. The extent of this wear is influenced by the additives and vegetable oil molecules, which form a thin, stable molecular layer that protects the metal. However, under high loads, the lubricant layer can be displaced, allowing direct contact between the metal surfaces and compromising this protection. In the current experimental setup, the lubricant creates a stable coating between the metals, and its ability to reduce wear depends on its stability and adhesion to the metal surface. SEM analysis of the worn track surfaces reveals the oil's structure, which is key to its stability.

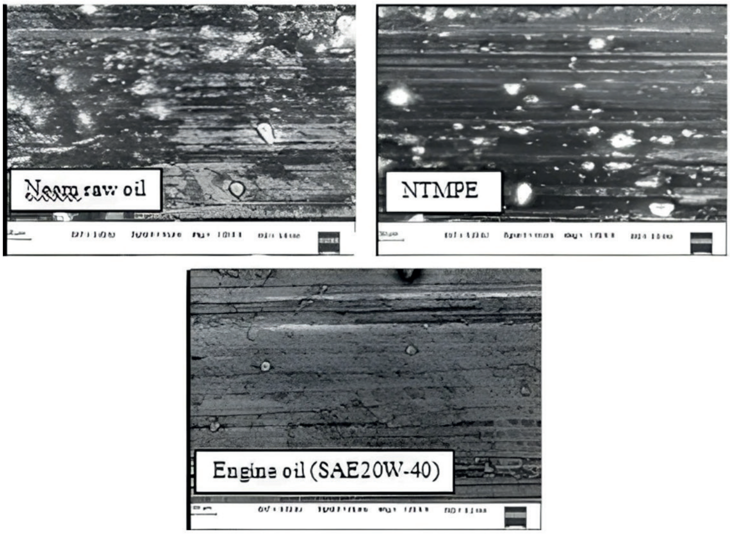

Fig. 10. SEM pictures of the worn pins surface for various lubricants

Figure 10 presents SEM micrographs of the worn pin surfaces lubricated with different oils. Surface analysis reveals that, unlike their unmodified counterparts, modified vegetable oil (NTMPE) lubricants form a stable layer between the hard disc surface and the pin. The presence of straight grooves and flakes on surfaces lubricated with unmodified vegetable oils suggests higher levels of abrasive and adhesive wear. In contrast, surfaces lubricated with modified vegetable oils do not exhibit these wear patterns. Lubrication with NTMPE shows superior film formation, consistent with the findings in Figures 8 and 9.

6. Conclusions

The experimental results indicate that lubrication with a blend of modified Neem oil and mineral oil outperforms lubrication with mineral oil alone. Specifically, the NTMPE20-MO80 blend enhances engine performance and reduces emissions compared to petroleum-based oil. Neem oil has a lower iodine value, which indicates a reduced level of unsaturation in its fatty acid profile. This characteristic enhances its oxidative stability, making it an effective base for lubricants. The high viscosity index of neem oil means that its viscosity changes minimally with temperature variations. This quality ensures reliable lubrication performance over a broad temperature spectrum, which helps to decrease wear and extend engine life. The NTMPE20-MO80 blend shows a slight improvement in mechanical efficiency, primarily due to the excellent lubricating properties of neem oil that lower internal friction among engine components, thus boosting overall efficiency. A notable 10% reduction in fuel consumption has been recorded with the NTMPE20–MO80 blend. The enhanced lubrication minimizes energy losses from friction, allowing a greater portion of the fuel's energy to be utilized effectively. Additionally, thermal efficiency improves by 9% when using the NTMPE20–MO80 blend, likely due to its ability to maintain optimal viscosity across various operating temperatures, which ensures consistent lubrication and reduces thermal losses. The NTMPE20–MO80 blend also leads to a 10% reduction in CO emissions, along with an 8% decrease in UHC emissions. This reduction is associated with more complete combustion, aided by improved lubrication that enhances sealing and fuel-air mixing efficiency. Furthermore, lubrication with the NTMPE20–MO80 blend results in a 5% reduction in wear compared to mineral oil. The polar ester groups present in neem oil create a protective layer on metal surfaces, preventing direct contact and thereby minimizing wear. An 8% decrease in the friction coefficient has also been noted with the NTMPE20–MO80 blend, as the superior lubricity of neem oil reduces resistance between moving parts, facilitating smoother operation and decreasing energy loss. SEM images reveal smoother surface textures on engine components lubricated with the NTMPE20-MO80 blend. This observation confirms the blend's effectiveness in minimizing surface wear and maintaining component integrity over time. Future research should use a typical engine, e.g. a car engine to examine the bio lubricant’s variability, while the current study focusses on a low-power single-cylinder petrol engine.

7. References

[1] Panchal TM, Patel A, Chauhan DD, Thomas M, Patel JV. A Methodological Review on Bio-Lubricants from Vegetable Oil Based Resources. Renewable and Sustainable Energy Reviews. 2017;70:65–70. https://doi.org/10.1016/j.rser.2016.11.105.

[2] Syahir AZ, Zulkifli NWM, Masjuki HH, Kalam MA, Alabdulkarem A, et al. A Review on Bio-Based Lubricants and Their Applications. Journal of Cleaner Production. 2017;168:997–1016. https://doi.org/10.1016/j.jclepro.2017.09.106.

[3] Cecilia JA, Plata BD, Saboya ARM, de Luna TFM, Cavalcante CL, Rodríguez-Castellón E. An Overview of the Biolubricant Production Process: Challenges and Future Perspectives. Processes. 2020;8(3):257. https://doi.org/10.3390/pr8030257.

[4] Heikal EK, Elmelawy MS, Khalil SA, Elbasuny NM. Manufacturing of environment friendly biolubricants from vegetable oils. Egyptian Journal of Petroleum. 2016;26(1):53–59. https://doi.org/10.1016/j.ejpe.2016.03.003.

[5] Sarma NR, Vinu R. Current Status and Future Prospects of Biolubricants: Properties and Applications. Lubricants. 2022;10(4):70. https://doi.org/10.3390/lubricants10040070.

[6] Shah R, Woydt M, Zhang S. The Economic and Environmental Significance of Sustainable Lubricants. Lubricants. 2021;9(2):21. https://doi.org/10.3390/lubricants9020021.

[7] Karmakar G, Ghosh P, Sharma B. Chemically Modifying Vegetable Oils to Prepare Green Lubricants. Lubricants. 2017;5(4):44. https://doi.org/10.3390/lubricants5040044.

[8] McNutt J, He Q. Development of biolubricants from vegetable oils via chemical modification. Journal of Industrial and Engineering Chemistry. 2016;36:1–12. https://doi.org/10.1016/j.jiec.2016.02.008.

[9] Mujtaba MA, Kalam MA, Masjuki HH, Soudagar MEM, Khan HM, Fayaz H, et al. Effect of Palm-Sesame Biodiesel Fuels with Alcoholic and Nanoparticle Additives on Tribological Characteristics of Lubricating Oil by Four Ball Tribo-Tester. Alexandria Engineering Journal. 2021;60(5):4537–4546. https://doi.org/10.1016/j.aej.2021.03.017.

[10] Gul M, Zulkifli NWM, Masjuki HH, Kalam MA, Mujtaba MA, Harith MH, et al. Effect of TMP-based-Cottonseed Oil Biolubricant Blends on Tribological Behavior of Cylinder Liner-Piston Ring Combinations. Fuel. 2020;278:118242. https://doi.org/10.1016/j.fuel.2020.118242.

[11] Menkiti MC, Ocholi O, Oyoh KB, Onukwuli OD. Synthesis and Tribological Evaluation of Sesame Oil-Based Trimethylolpropane Ester. Journal of the Chinese Advanced Materials Society. 2015;3(2):71–88. https://doi.org/10.1080/22243682.2015.1013154.

[12] Shahabuddin M, Mofijur M, Kalam MA, Masjuki HH. Study on the Friction and Wear Characteristics of Bio-lubricant Synthesized from Second Generation Jatropha Methyl Ester. Tribology in Industry. 2020;42(1):41–49. DOI: 10.24874/ti.2020.42.01.04.

[13] Mahara M, Singh Y. Tribological Analysis of the Neem Oil during the Addition of SiO2 Nanoparticles at Different Loads. Materials Today: Proceedings. 2020;28(3):1412–1415. https://doi.org/10.1016/j.matpr.2020.04.813.

[14] Zaid M, Kumar A, Singh Y. Lubricity Improvement of the Raw Jojoba oil with TiO2 Nanoparticles as an Additives at Different Loads Applied. Materials Today: Proceedings. 2021;46(9):3165–3168. https://doi.org/10.1016/j.matpr.2020.07.437.

[15] Jabal MH, Abdulmunem AR, Abd HS. Experimental Investigation of Tribological Characteristics and Emissions with Nonedible Sunflower Oil as a Biolubricant. Journal of the Air & Waste Management Association. 2019;69(1):109–118. https://doi.org/10.1080/10962247.2018.1523070.

[16] Singh P, Goel V. Effect of Bio-Lubricant on Wear Characteristics of Cylinder Liner-Piston Ring and Cam-Tappet Combination in Simulated Environment. Fuel. 2018;233:677–684. https://doi.org/10.1016/j.fuel.2018.06.092.

[17] Ruggiero A, D'Amato R, Merola M, Valášek P, Müller M. On the Tribological Performance of Vegetal Lubricants: Experimental Investigation on Jatropha Curcas L. Oil. Procedia Engineering. 2016;149:431–437. https://doi.org/10.1016/j.proeng.2016.06.689.

[18] Sapawe N, Samion S, Zulhanafi P, Nor Azwadi CS, Hanafi MF. Effect of Addition of Tertiary-Butyl-Hydroquinone into Palm Oil to Reduce Wear and Friction Using Four-Ball Tribotester. Tribology Transactions. 2016;59(5):883–888. https://doi.org/10.1080/10402004.2015.1118584.

[19] Singh Y. Tribological Behavior as Lubricant Additive and Physiochemical Characterization of Jatropha Oil Blends. Friction. 2015;3(4):320–332. https://doi.org/10.1007/s40544-015-0095-1.

[20] Wan Q, Jin Y, Sun P, Ding Y. Tribological Behavior of a Lubricant Oil Containing Boron Nitride Nanoparticles. Procedia Engineering. 2015;102:1038–1045. https://doi.org/10.1016/j.proeng.2015.01.226.

[21] Ribeiro Filho PRCF, Nascimento MR, da Silva SSO, de Luna FMT, Rodríguez-Castellón E, Cavalcante Jr CL. Synthesis and Frictional Characteristics of Bio-Based Lubricants Obtained from Fatty Acids of Castor Oil. Lubricants. 2023;11(2):57. https://doi.org/10.3390/lubricants11020057.

[22] Ismaila SS, Sani Y, Sani AA, Yakasai SM, Momoh H, Sa'adatu EM. Determination of Fatty Acids and Physicochemical Properties of Neem (Azadrachta Indica L) Seed Oil Extracts. Dutse Journal of Pure and Applied Sciences. 2022;8(1a):149–160. https://doi.org/10.4314/dujopas.v8i1a.16.

[23] Girish AR, Shashidhara YM. Study on Performance and Emission Characteristics of Four stroke Gasoline engine under Formulated Neem oil as base lubricant. IOP Conference Series Materials Science and Engineering. 2021;1189(1):012014. https://doi.org/10.1088/1757-899X/1189/1/012014.

[24] Kumar A, Kumar R, Kumar S. A Study On Microstructural And Mechanical Properties Effected By Different Heat Treated Of Aisi 1055 Steel. International Journal of Advances in Engineering and Management. 2020;2(6):38–50. https://doi.org/10.35629/5252-02063850.