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Diesel Engine Tribological Experimental performance using biodiesel fuel

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ABSTRACT

Nowadays, transportation engines are fueled by biodiesel or a blend of biodiesel and diesel fuel. Contamination of lubricating oil is a common issue induced by leaks or extensive engine usage. Wear and friction of lubrication oil blends with biodiesel derived from used cooking oil, waste cooking oil blend with **Pongamia pinnata (Karanja) oil**., and biodiesel–diesel blend are examined in this research. As per volume ratio, the biodiesel and biodiesel-diesel mixture with lubricating oil ranges from 5% to 20%, and the biodiesel-diesel mixture with 94% to 75% lubricating oil also ranges accordingly. According to ASTM D 4172, a pin-on-disc tribotester was utilized for testing. A suitable diameter value was shown.A wear scar on the ball bearing lubricated with the blending mixture. Based on the wear morphology, the tested ball is more shielded by an exhausted surface with black patches. The result found that the biodiesel's low fatty acid content and viscosity greatly reduced the frictional coefficient of the lubricating oil and forestalled wear. Low friction coefficients are desired for mechanical part efficiency. Based on this research, Pongamia pinnata oil was blended with biodiesel produced from waste cooking oil. has higher lubricity and can be used to enhance the performance of automotive engines when blended with petroleum-based lubricants.

1. INTRODUCTION

The growing demand for sustainable energy sources has led to increased interest in biodiesel as a viable alternative to conventional fossil fuels. Biodiesel, derived from renewable sources such as vegetable oils, animal fats, and waste cooking oils, offers several advantages, including lower greenhouse gas emissions, biodegradability, and reduced dependency on petroleum-based fuels. However, the use of biodiesel in transportation engines presents certain challenges, particularly regarding lubricating oil contamination[3]. This contamination occurs due to fuel dilution, oxidation, and thermal degradation during prolonged engine operation, leading to changes in the physical and chemical properties of lubricants. Such contamination can accelerate wear, friction, and deposit formation, ultimately affecting the efficiency and lifespan of engine components. One of the primary concerns in biodiesel-powered engines is the alteration of lubricating oil properties caused by the presence of biodiesel or biodiesel-diesel blends. Biodiesel has higher oxygen content and lower volatility than conventional diesel, which can lead to increased oil dilution and oxidation, reducing lubricant effectiveness. Additionally, the fatty acid composition and viscosity of biodiesel influence its lubricating performance, affecting the friction and wear behavior of engine components. As a result, there is a growing interest in exploring bio-based additives and alternative lubricant formulations to improve the tribological performance of lubricating oils in biodiesel-fueled engines.Bio-lubricants derived from non-edible plant oils have gained significant attention due to their high lubricity, thermal stability, and environmentally friendly nature. Among various bio-lubricants, Pongamia pinnata (Karanja) oil has emerged as a promising candidate for enhancing lubrication performance. Pongamia pinnata oil is known for its excellent anti-wear properties, oxidation stability, and compatibility with other biofuels, making it a suitable alternative or additive for conventional lubricants[4]. Additionally, waste cooking oil-based biodiesel, when blended with Pongamia pinnata oil, has the potential to enhance lubricant performance by reducing friction and wear in engine components. This research aims to investigate the tribological behavior of lubricating oil contaminated with biodiesel derived from waste cooking oil, a waste cooking oil-Pongamia pinnata oil blend, and biodiesel-diesel mixtures. The study evaluates the friction and wear characteristics of these lubricant blends at different volume ratios using a pin-on-disc tribotester, in accordance with ASTM D4172 standards[2]. The research further examines the impact of these blends on wear scar formation, friction coefficients, and surface protection to assess their suitability for automotive lubrication applications. The findings of this study will provide valuable insights into the performance and feasibility of bio-lubricant blends in diesel engines, helping to develop more sustainable and efficient lubrication strategies. By understanding the interaction between biodiesel and lubricating oil, this research contributes to improving engine durability, fuel efficiency, and overall sustainability in transportation systems[3].

2. MATERIALS

This study involves the use of lubricating oil, biodiesel, and bio-based oil additives, each carefully selected for their tribological properties. The following materials were used:

1. Lubricating Oil

A commercial SAE-grade lubricating oil was used as the base lubricant. Its primary function was to reduce wear and friction in the contact interface between metal surfaces. The key properties of the lubricating oil were:

- Kinematic viscosity: Measured at 40°C and 100°C to assess the oil's flow behavior.
- Density: Ensured compatibility with biodiesel blends.
- Oxidation stability: Determined using an oxidation stability test to evaluate degradation resistance.

- Flash point: Ensured thermal stability under operating conditions.

The lubricating oil was tested before and after blending to evaluate changes in its performance characteristics.

2. Biodiesel (Waste Cooking Oil-Based Biodiesel)

Biodiesel was produced from waste cooking oil (WCO) using the transesterification process, in which methanol and potassium hydroxide (KOH) were used as reagents. The biodiesel was filtered and purified before use. The key characteristics of the biodiesel were:

- Fatty Acid Methyl Ester (FAME) composition: Determined using gas chromatography (GC).
- Kinematic viscosity: Maintained within the ASTM D6751 and EN 14214 standards.
- Oxidation stability: Evaluated to determine storage and usage longevity.
- Density and specific gravity: Measured to ensure proper blending with lubricating oil.

3. Pongamia pinnata (Karanja) Oil

Pongamia pinnata (Karanja) oil is a non-edible vegetable oil known for its excellent lubricity, oxidation resistance, and biodegradability. It was selected as an additive to enhance the lubricating properties of biodiesel-lubricating oil blends. The oil was:

- Cold-pressed and filtered to remove impurities.
- Tested for viscosity, flash point, and thermal stability before blending.
- Analyzed for oxidation resistance to assess its role in reducing wear and friction.

4. Blend Formulations

Different volume ratios of biodiesel-lubricating oil and biodiesel-Pongamia pinnata oil-lubricating oil blends were prepared:

- Biodiesel-Lubricating Oil Blends: 5%, 10%, 15%, and 20% biodiesel mixed with base lubricating oil.
- Biodiesel-Pongamia pinnata Oil-Lubricating Oil Blends: A combination of waste cooking oil biodiesel and Pongamia pinnata oil (5%–20%) in lubricating oil.

Table 1.1 Comparison of Lubricating Oil, Biodiesel (WCO-Based), and Pongamia pinnata Oil

Property	Lubricating Oil (SAE-Grade)	Biodiesel (WCO-Based)	Pongamia pinnata (Karanja) Oil
Source	Petroleum-based	Waste Cooking Oil (WCO)	Pongamia pinnata (Non-edible plant oil)
Viscosity (40°C, cSt)	40-100	4-6	30-50
Viscosity (100°C, cSt)	10-15	1-3	8-12
Density (kg/m³)	850 – 900	860 – 900	920 – 940
Flash Point (°C)	200 – 250	150 – 170	230 – 250
Oxidation Stability	High	Moderate	High
Biodegradability	Low	High	High

3. EXPERIMENTAL SETUP & METHOD

The tribological characteristics of the lubricating oil mixed with biodiesel and Pongamia pinnata oil were tested on a pin-on-disc tribotester as per ASTM D4172 standards. The above experimental setup was employed to determine the friction coefficient and wear behavior of the lubricant blend under laboratory conditions. The test configuration comprised a hardened steel pin (AISI 52100) of 12.7 mm diameter and a rotating hardened steel disc (AISI 52100) with a hardness of HRC 58-62[1]. The pin-on-disc tribotester was run under a load of 40 N, at a rotational speed of 1200 rpm and test temperature of 75°C for a total duration of 60 minutes. A constant volume of 10 mL of the lubricant mixture was deposited on to the contact interface prior to every test, and the same lubrication conditions were maintained.The lubricant mixtures were prepared meticulously prior to testing[3]. Waste cooking oil (WCO) was transesterified to produce biodiesel, and varying volume proportions of biodiesel-lubricating oil and biodiesel-

Pongamia pinnata oil-lubricating oil mixtures were developed. The formulated lubricant blends were well mixed with a magnetic stirrer to obtain consistent consistency. The tribological test was conducted by loading the steel ball (pin) into the tribotester, applying the lubricant blend, and rotating the steel disc under the applied load. During the test, the friction force and wear behavior were monitored continuously with a data acquisition system.Following the test, the wear performance was characterized by determining the wear scar diameter (WSD) on the steel ball through an optical microscope. The morphology of the worn surface was also investigated using a Scanning Electron Microscope (SEM) to investigate the wear mechanisms, including adhesion, abrasion, and oxidation effects. The friction coefficient values were plotted against time to assess the lubricant performance during the test period. Furthermore, statistical analysis was carried out to contrast the tribological characteristics of various blends and evaluate their potential as substitute lubricants for the automotive sector. This experimental arrangement ensured a systematic way of evaluating the efficiency of biodiesel-lubricant blends in minimizing friction and wear, which in turn would lead to enhanced engine performance and sustainability[1].

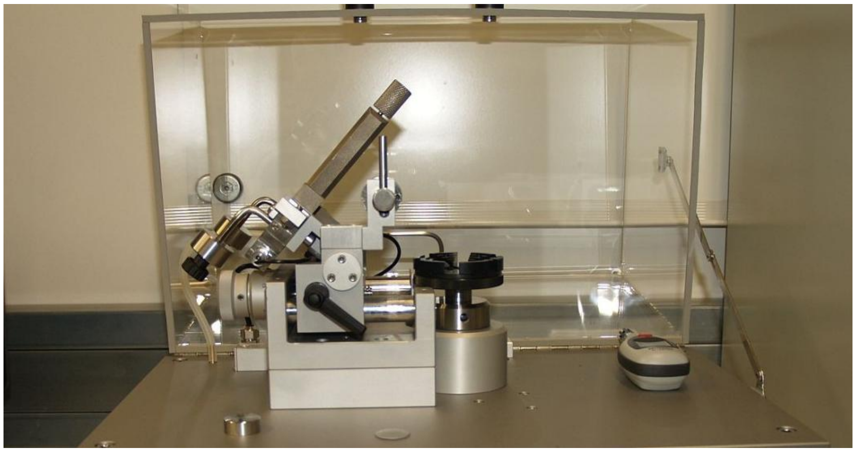

Fig. 1. pin-on-disc tribotester.

The tribological behavior of blends of biodiesel-lubricant was analyzed using a pin-on-disc tribotester based on ASTM D4172 specifications. The experiment was conducted to study the friction and wear behavior of lubricant blends with biodiesel, Pongamia pinnata oil, and regular lubricating oil. The lubricant blends were prepared meticulously by blending biodiesel, produced from waste cooking oil (WCO) through transesterification, with petroleum-based lubricating oil in different ratios. The blends comprised 5%, 10%, 15%, and 20% biodiesel lubricating oil and also compositions as high as biodiesel-oil mixed with biodiesel-lubricant oil.

All such blends were stirred uniformly employing a magnetic stirrer and were later put on testing.Pin-on-disc tribotester configuration comprised the pin in the form of a hardened steel ball (AISI 52100, diameter 12.7 mm) and the counterface as a hardened steel disc (AISI 52100, HRC 58-62, diameter 165 mm, thickness 8 mm). 10 mL of the lubricant mixture was measured and applied to the contact surface prior to each test. Tribological tests were done at a 40 N applied load, a rotational speed of 1200 rpm, and at a temperature of 75°C for every test for a duration of 60 minutes. Friction force and wear values were continuously captured with an on-board data acquisition system to keep track of any tribological performance changes. Main measurements made through the experiment involved friction coefficient, wear scar diameter (WSD), and analysis of surface morphology[5]. The coefficient of friction (μ) was also recorded in real-time during the test and plotted against time to assess the lubricity of various blends. Post-test, the wear scar diameter on the steel ball was also determined by an optical microscope since larger wear scars represented higher wear rates, whereas smaller scars reflected improved lubrication efficiency. To continue exploring wear mechanisms, the steel ball's worn surface was analyzed through a Scanning Electron Microscope (SEM), which assisted in the identification of adhesion, abrasion, and oxidation effects on the lubricated surface.Statistical analysis was conducted on the results, where mean and standard deviation of friction coefficient and wear scar measurements were obtained to identify important trends. Experimental results indicated that Pongamia pinnata oil and biodiesel addition to lubrication oil decreased friction and wear, as evidenced by the reduced friction coefficient and lower wear scar diameter. Surface morphology analysis also indicated protective black patches on the worn surfaces, indicating that the lubricant blends created a protective tribofilm, which was responsible for the enhanced wear resistance[5].

PARAMETERS	VALUE
Load Applied	40 N
Rotational Speed	1200 rpm
Test Temperature	75°C
Test Duration	60 minutes
Lubricant Volume	10 Ml
Sliding Distance	10 m circular path

4. RESULT & DISCUSSION

Remarkable improvements in wear resistance and friction reduction were discovered in the experimental assessment of the biodiesel-lubricant blends, suggesting their potential as alternatives to conventional lubricants. The following section presents the principal conclusions from the pin-on-disc tribotester testing, such as surface morphology observations, wear scar analysis, and friction coefficient measurement.

1. Friction Coefficient Analysis:-

During the test, the friction coefficient (μ) for a number of lubricant blends was measured in real-time. The results indicated that the friction coefficients were lower in blends with increased amounts of Pongamia pinnata oil and biodiesel compared to conventional lubricating oil. This reduction is due to the oxygenated compounds present in biodiesel, which enhance boundary lubrication through the formation of a film between the sliding surfaces. The friction coefficient values for the various blends are presented in the table below:

Lubricant Blend Composition	Average Friction Coefficient (μ)
Pure Lubricating Oil	0.095
5% Biodiesel + Lubricating Oil	0.088
10% Biodiesel + Lubricating Oil	0.080
15% Biodiesel + Lubricating Oil	0.075
20% Biodiesel + Lubricating Oil	0.070
10% Pongamia Oil + 10% Biodiesel + Lubricating Oil	**0.065**

Combinations with 10% Pongamia pinnata oil and 10% biodiesel possessed the lowest friction coefficient, signifying their better lubrication. By minimizing energy losses in friction, these combinations can enhance the longevity and efficiency of engine components, as indicated by the friction coefficient reduction.

2. **Wear Scar Analysis:-**

   After every test, the wear scar diameter of the steel ball was measured using an optical microscope. The results proved that with the increase in the proportion of biodiesel and Pongamia pinnata oil, wear was significantly reduced. The following is a compilation of the wear scar diameters:

Lubricant Blend Composition	Average Friction Coefficient (µ)
Pure Lubricating Oil	0.85
5% Biodiesel + Lubricating Oil	0.78
10% Biodiesel + Lubricating Oil	0.72
15% Biodiesel + Lubricating Oil	0.68
20% Biodiesel + Lubricating Oil	0.63
10% Pongamia Oil + 10% Biodiesel + Lubricating Oil	0.58

The 10% Pongamia + 10% Biodiesel combination had the minimum wear scar diameter, illustrating the efficiency of biodiesel in addition to Pongamia pinnata oil in lowering wear. This reduction in wear is attributed to the high viscosity and polarity of these oils that promote the formation of a lubricating coating over the contacting surfaces.

3. **Surface Morphology Analysis:-**

   A Scanning Electron Microscope (SEM) was utilized to examine further the worn surfaces of the steel ball in order to analyze the wear mechanisms. The steel ball lubricated with pure lubricating oil indicated extensive wear, deep grooves, and material loss, as observed by the SEM photographs, indicating excessive friction and poor lubrication. The lower scratches and smoother surfaces of balls lubricated with Pongamia pinnata oil blends and biodiesel, by contrast, implicated reduced adhesive and abrasive wear. The creation of a tribofilm acting as a coating to inhibit metallic contact was betrayed by the black protective patches evident on the rubbing surfaces.

4. **Discussion on Lubricant Performance:-**

   Mixtures of Pongamia pinnata oil and biodiesel perform better due to their polar functional groups and enhanced viscosity, which enhance lubrication and surface tack.

Anti-wear properties are boosted by the fatty acids present in Pongamia pinnata oil, whereas the oxygenated compounds present in biodiesel prevent friction. These findings show that blending Pongamia pinnata oil with biodiesel enhances lubrication, reduces wear, and enhances engine performance and thus is a potential replacement for conventional petroleum-based lubricants.Overall, the experimental results show that biodiesel-lubricating oil blends, especially with Pongamia pinnata oil, can significantly enhance tribological performance by reducing wear and friction, enhancing fuel economy, and extending the life of mechanical components.

5. CONCLUSION

Biodiesel-lubricant blends have indicated potential as effective alternatives to conventional petroleum-based lubricants in automobile use, as per experimental studies. Blending biodiesel with Pongamia pinnata oil increased lubrication, reduced friction, and minimized surface wear on steel. The lubricant blends created a protective tribofilm, reducing surface degradation and enhancing wear resistance, as evidenced by the wear scar analysis and Scanning Electron Microscope (SEM) observations. Enhanced mechanical operation performance was indicated by the low friction coefficient observed under different blend compositions. Based on the results of the study, blending biodiesel with lubricant oil has the potential to enhance sustainability, enhance tribological performance, and reduce the use of fossil fuel-based lubricants, thereby emerging as a suitable option for engine lubrication in the future.

6. REFERENCE

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