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ENHANCED THERMO-OXIDATIVE AND TRIBOLOGICAL PROPERTIES OF OLEIC ACID-BASED LUBRICANT WITH ANTIOXIDANTS AND VISCOSITY IMPROVER

Amanda Maisarah Norazman*, Zulhanafi Paiman , Syahrullail Samion
Faculty of Mechanical Engineering, Universiti Teknologi Malaysia,
81310 UTM Johor Bahru, Johor, Malaysia.
* Corresponding author: amandamaisarah@graduate.utm.my

ABSTRACT

The growing environmental concerns associated with mineral-based lubricants have driven interest in biodegradable alternatives such as biolubricants. Oleic acid, a monounsaturated fatty acid derived from palm oil, presents promising tribological properties but suffers from oxidative instability. In this study, oleic acid-based lubricants were enhanced with three phenolic antioxidants—tert-butyl hydroquinone (TBHQ), butylated hydroxyanisole (BHA), and butylated hydroxytoluene (BHT)—at a concentration of 1%, along with a viscosity modifier, ethylene-vinyl acetate (EVA), at 1.2%. Tribological performance was assessed using the four-ball wear test (ASTM D4172) under a load of 392 N, speed of 1200 rpm, and temperature of 75°C.

The coefficient of friction (COF) and wear scar diameter (WSD) were used as key performance indicators. Oleic acid exhibited the lowest COF, improving by 32.8% compared to commercial Shell lubricant, while BHA and TBHQ followed closely with 27.7% and 25.5% improvement, respectively. For anti-wear performance, TBHQ yielded the lowest WSD, outperforming Shell by 14.6%. These results indicate that while oleic acid excels in friction reduction, TBHQ provides the most balanced performance by enhancing both friction and wear resistance.

The addition of phenolic antioxidants notably improves the tribological behavior of oleic acid-based biolubricants. Further analysis using SEM-EDX, DSC, and TGA-DTG is recommended to evaluate oxidation mechanisms and thermal stability, thereby supporting their viability as environmentally friendly alternatives in industrial lubrication applications.

KEYWORD
Oleic acid, biolubricant, antioxidant, phenolic, viscosity improver

INTRODUCTION

Mineral- and conventional-based lubricants have been used since the advent of automobiles in the 1800s. These lubricants are derived from non-renewable sources such as petroleum and other fossil fuels. However, their widespread use raises environmental concerns, particularly regarding their disposal. Improper disposal of fossil-based lubricants can lead to significant pollution of aquatic ecosystems, transforming waterways into toxic wastelands (Singh *et al.*, 2017).

Biolubricants, derived from biodegradable and renewable resources, have emerged as a promising alternative to mineral-based lubricants. These lubricants can be produced from a wide range of sources, including vegetable oils such as palm oil, coconut oil, and sunflower oil, as well as non-vegetable sources like sewage sludge, microbial oils, and non-edible oils such as castor oil. In this study, oleic acid, a monounsaturated fatty acid with 18 carbon atoms and a signle double bond is used as the base material. Derived from palm oil, oleic acid is valued for its favorable properties, including optimal viscosity, good thermo-oxidative stability and favorable melting points (McNutt and He, 2016).

To perform effectively under real-world operating conditions, biolubricants must maintain stable properties, particularly in terms of viscosity and oxidative resistance. Oleic acid, despite its advantageous base characteristics, is inherently prone to oxidative degradation when exposed to heat, air, and mechanical stress. To address this, antioxidants are incorporated into the formulation. These compounds scavenge free radicals, interrupting chain oxidation reactions and thereby stabilizing the lubricant (Chandra et al., 2020).

Phenolic antioxidants such as tert-butylhydroquinone (TBHQ), butylated hydroxyanisole (BHA), and butylated hydroxytoluene (BHT) are commonly employed for this purpose due to their high oxidative resistance and compatibility with fatty acid-based systems. In addition to antioxidants, ethylene-vinyl acetate (EVA) is often used as a viscosity modifier to further enhance the rheological behavior of the lubricant, ensuring performance consistency across a wide temperature range.

Although many studies have demonstrated the potential of oleic acid as a biolubricant, its standalone performance remains limited without chemical modification or the inclusion of performance-enhancing additives. In tribological applications, lubricant performance is typically evaluated through parameters such as the coefficient of friction (COF) and wear scar diameter (WSD), along with other machine-specific metrics. Therefore, comprehensive physico-chemical and tribological testing is essential to optimize the formulation and ensure reliable, real-world applicability.

MATERIAL AND METHODOLOGY

Oleic acid with a purity of 75% was procured from Evyap Sdn. Bhd. The tribological tests were conducted using a four-ball tester operated at 1200 rpm and 75°C for a duration of one hour, following the ASTM D4172 standard. Each test was repeated three times to ensure reproducibility, and the average values of the coefficient of friction (COF) and wear scar diameter (WSD) were calculated, with standard deviations used to represent measurement variability as error bars. Antioxidants TBHQ, BHA, and BHT were each incorporated into the oleic acid at a concentration of 1%, while the viscosity improver, ethylene-vinyl acetate (EVA), was added at 1.2%. The experimental setup is illustrated in Figure 1.

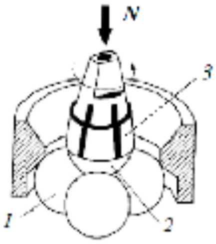

Figure 1: Four-ball tester mechanism (Al-Quraan *et al.*, 2023)

In this configuration, the rotating ball (2) is held in place by a collet (3), while the three stationary balls (1) are positioned beneath it. Following testing, the wear scars on the stationary balls were examined under a microscope to assess wear characteristics. Key tribological parameters including wear scar diameter, coefficient of friction, and wear mechanisms were determined from the four-ball test. The steel balls used in the test each have a diameter of 12.7 mm, with the applied load and rotational speed fixed at 392 N and 1200 rpm, respectively. Labelling conventions for the test samples are summarized in Table 1.

Table 1: Guide for graph labelling

Lubricant	Label
Oleic acid + 1% TBHQ + 1.2% EVA	OA+TBHQ
Oleic acid + 1% BHA + 1.2% EVA	OA+BHA
Oleic acid + 1% BHT + 1.2% EVA	OA+BHT
Oleic acid	OA
Shell Tellus 68	SHELL

RESULT AND DISCUSSION

As shown in Figure 2, oleic acid demonstrated the lowest coefficient of friction (COF), exhibiting a 32.8% improvement compared to the commercial reference lubricant, Shell. Among the antioxidant-enhanced formulations, BHA yielded the second-best performance with a 27.7% improvement, followed by TBHQ at 25.5%, and BHT at 14%. The superior performance of phenolic antioxidants is attributed to the presence of hydroxyl (-OH) groups, which readily donate hydrogen atoms. These hydrogen atoms neutralize free radicals by stabilizing unpaired electrons, thereby interrupting the oxidation chain reaction and enhancing oxidative stability.

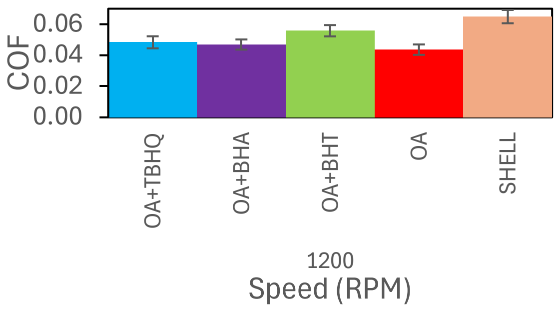

Figure 2: Friction coefficient against speed

Figure 3 presents the wear scar diameter (WSD) results. TBHQ showed the most favorable anti-wear performance, with a 14.6% reduction in WSD compared to Shell. In contrast, BHA, BHT, and pure oleic acid (OA) exhibited larger WSD values—11.6%, 42%, and 24.1% higher than Shell, respectively. This finding aligns with previous work by Sapawe *et al.*, (2016), who reported that incorporating TBHQ into palm oil significantly reduced wear scar formation. TBHQ not only enhances oxidative resistance but also forms a protective lubricating layer at the metal contact interface, thereby improving anti-wear characteristics. A recent study by Hou *et al.*, (2024) further supports this, showing that the addition of TBHQ to a castor oil-based biolubricant improved COF by 31% and simultaneously minimized wear scar diameter.

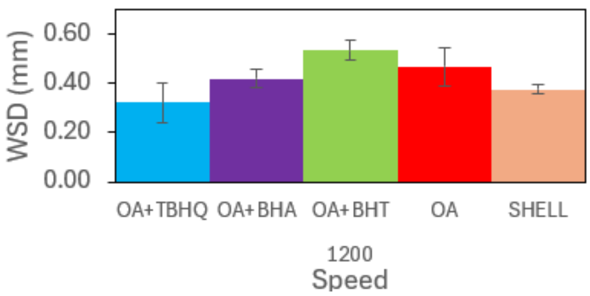

Figure 3: Wear scar diameter (WSD) against speed

CONCLUSION

In conclusion, TBHQ and BHA exhibited comparable performance in terms of friction reduction, with only a marginal difference of approximately 2% in their coefficient of friction (COF). Although oleic acid recorded the lowest COF among all tested lubricants, it is essential to consider additional factors such as oxidative and thermal stability when evaluating overall lubricant performance. In terms of wear protection, TBHQ outperformed all other formulations, including the commercial reference Shell, demonstrating a 14.6% lower wear scar diameter (WSD).

Further investigation is necessary to comprehensively evaluate the physicochemical properties of these formulations. Future work should include advanced characterization techniques such as scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX) for wear surface analysis, differential scanning calorimetry (DSC) for oxidative stability, and thermogravimetric analysis (TGA-DTG) to assess thermal degradation behavior.

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