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COMPARATIVE ANALYSIS OF SINGLE AND HYBRID NANOPARTICLE ADDITIVES IN MODIFIED JATROPHA OIL FOR ECO-FRIENDLY METALWORKING APPLICATIONS

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ABSTRACT

Metalworking fluids (MWFs) are crucial for reducing wear and friction during machining processes. Vegetable oils, known for their excellent lubricating qualities, are highly biodegradable, non-toxic, and cost-effective to produce, making them an ideal alternative to mineral oils in metalworking applications. The incorporation of nanoparticles into vegetable oil is a viable strategy for improving the lubricating capabilities of MWFs. The aim of this study was to assess the physical and tribological properties of modified jatropha oil (MJO) with 0.025 wt. % of additives. MJOaw (activated carbon and tungsten disulfide) exhibited the highest VI of 377 and the lowest COF (0.05596). The results of the physical and tribological evaluations provide valuable insights into the performance of these nanofluids, paving the way for their potential application in efficient and eco-friendly metalworking processes.

KEYWORD

Modified jatropha oil, hybrid nanofluids, tribology

INTRODUCTION

The increasing awareness of environmental issues, coupled with more stringent regulatory measures, has intensified the pursuit of sustainable and eco-friendly alternatives to conventional mineral-based metalworking fluids. In response, there has been a shift towards renewable alternatives, and jatropha curcas oil has emerged as a promising non-edible feedstock for bio-lubricant production. Its abundant availability, renewability, and superior lubrication properties, including high viscosity and favorable wear characteristics compared to mineral oils, make it suitable for replacing petroleum-based lubricants (Ifeanyi-Nze & Akhiehiero, 2023).

The incorporation of nanoparticles into lubricants has revolutionized tribological performance by addressing the key limitations of conventional base oils. The additional of WS_2 nanoparticles enhance lubrication through surface film formation and anti-corrosion properties, reducing wear rates by mechanisms associated with both viscosity modulation and interfacial protection (Sabri et al., 2024a). In addition, AC nanoparticles, with their porous structure and high surface area, act as spacers between sliding surfaces, preventing direct metal-to-metal contact and reducing wear by up to 3.21 times at optimal concentrations (Talib et al., 2022). Hybrid nanofluids, which contain two or more distinct nanoparticle types, exploit synergistic effects to overcome the limitations of individual particles while enhancing overall performance (Rahman et al., 2022). This study investigates the physical and tribological properties of modified jatropha-based nanofluids for application as metalworking fluids, utilizing both single nanoparticles and hybrid combinations.

MATERIAL AND METHODOLOGY

Nanofluids Preparation

Crude jatropha oil (CJO) undergoes chemical modification through an acid-based catalyst transesterification process to produce jatropha methyl ester (JME). Subsequently, JME reacts with trimethylolpropane (TMP) in the presence of sodium methoxide ($NaOCH_3$) as a catalyst, resulting in modified jatropha oil (MJO). The MJO is then incorporated with single and hybrid nanoparticles. Specifically, MJO was mixed with 0.025 wt. % of AC (MJOa) and hybrid nanoparticles AC + WS_2

(MJOaw), respectively. The incorporation of nanoparticles into the MJO was achieved through a three-step process to ensure homogeneity. The samples were compared with a synthetic ester (SE, Unicut Jinen MQL).

Physical Testing

The viscosity index (VI) of the MJO samples was calculated according to ASTM D4502. The VI was calculated from the kinematic viscosity between the temperatures of 40 °C and 100 °C.

Tribological Testing

Tribological evaluation was conducted using a DUCOM TR-30L four-ball tribotester, adhering to the ASTM D4712 standard. Each experiment utilized four steel balls made of AISI 52100. A volume of ten milliliters of lubricant sample was introduced into the ball port. The three stationary balls were secured within the ball pot assembly, and the rotating ball was inserted into the collet and positioned within the spindle. Subsequently, the ball port was installed in the tribotester machine, and a load of 392 N was applied gradually. The temperature of the oil heater was regulated to 75±2°C. Upon reaching the desired temperature, the rotating ball was operated at a constant speed of 1200 rpm for 60 min. The coefficient of friction (COF) was calculated using Winducom software based on the friction torque results.

RESULT AND DISCUSSION

Figure 1 illustrates the viscosity index (VI) and coefficient of friction (COF) for all lubricant samples. The SE had a lower VI at 147 compared to the MJO(343). In addition, SE had a higher COF (0.1037) than MJO (0.0615). The MJO (343) exhibited a high VI, indicating superior stability across a broad temperature range. The elevated VI of the MJO lubricant samples implies that their viscosity undergoes minimal alteration and remains stable in response to temperature fluctuations (Saka et al., 2025). This stability ensures the preservation of the viscosity and lubricating properties of the lubricant, thereby providing consistent protection during four-ball testing and resulting in a lower COF than that of SE. The addition of a single activated carbon (AC) nanoparticle (MJOa) slightly increased the VI of MJO by 6% (364). The low thermal expansion coefficient of AC (3.6×10^{-6} $^{o}C^{-1}$) improved the thermal stability of the base oil. Furthermore, MJOa demonstrated a 4% reduction in the COF compared with MJO and a 43% reduction compared with SE. This phenomenon can be attributed to a decrease in the contact pressure, which is influenced by the rolling and mending mechanisms facilitated by the presence of AC in the surface valleys. This alteration in the sliding friction results in a rolling effect within the contact region (Solomon et al., 2023). Interestingly, the addition of hybrid AC with tungsten disulfide (WS_2) nanoparticle additives increased the VI of MJO by 9.0% and MJOa by 3.4%. The VI of MJOaw(377) was the highest among all lubricant samples and exhibited the lowest COF (0.05596) among all lubricant samples. The MJOaw reduced the COF by 9% compared to the MJO and by 5% compared to the MJOa. The synergistic mechanism of the hybrid AC with WS_2 nanoparticle additives in the base oil is attributed to the sliding friction of the metal being mitigated by the depositional coating formed by the hybrid nanoparticles. Furthermore, the formation of a lubricating iron sulfide (FeS) layer, also known as a tribochemical film, significantly reduces the COF by preventing direct contact between the surfaces of the friction pairs (Sabri et al., 2024b).

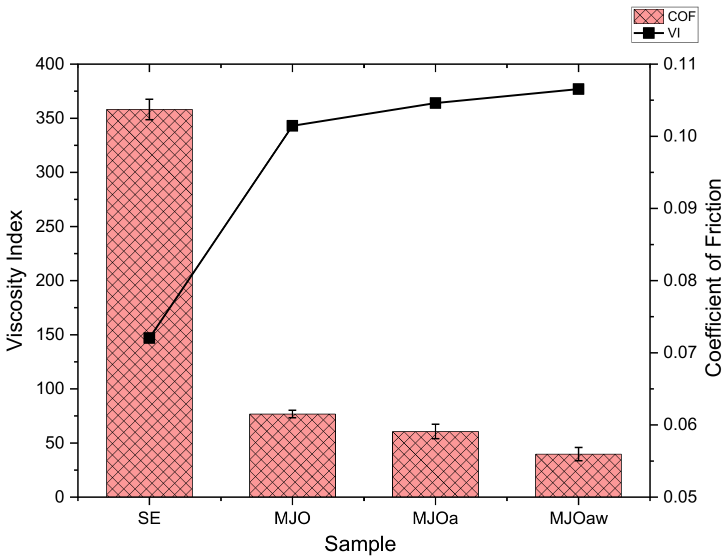

Figure 1: Graph of viscosity index and coefficient of friction (COF) for all lubricant samples.

CONCLUSION

In conclusion, the integration of nanoparticles into the MJO enhanced its lubrication and tribological properties. The results indicate that MJOaw exhibits improved VI and tribological performance, making it the most suitable candidate for an environmentally friendly MWF in machining processes.

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