Improving Thermal and Tribological Properties of Enhanced Biolubricant with Graphene and Maghemite Nano-additives

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Abstract. Failure of biolubricants at elevated temperature hinder their efficient performance. These challenges are ameliorated using nano-additives to enhance the thermal and anti-wear properties of lubricants. In this study, coconut oil as base fluid was dispersed with 0.1% volume concentration of maghemite (γFe2O3) and exfoliated graphene (XGnP) nano-additives. Thermogravimetric analysis (TGA) was performed using thermal analyser to evaluate thermal degradation of nanolubricants and the base oil. In addition, anti-wear properties and viscosity of base coconut oil and the enhanced nanolubricants were evaluated. The TGA results indicates that oxidation onset temperature was retarded by 9 °C and 31.82 °C for maghemite (MGCO) and graphene (XGCO) enhanced nanolubricants respectively in comparison with base coconut oil (CCO). Friction reduction and anti-wear property of the nanolubricants showed better performance over the base oil. For graphene enhanced nanolubricant, a reduction of 10.4% and 5.6% in terms of COF and WSD respectively was observed while 3.3% and 4.3% reduction in COF and WSD respectively for maghemite enhanced nanolubricant when compared with the base oil (CCO). The excellent property improvement of thermal stability and tribological properties makes the enhanced lubricants a suitable candidate for consideration as machining lubricants.

Keywords: Nanolubricant · Friction · Wear · Thermal stability · Viscosity

1 Introduction

Lubricants are used to perform several functions such as friction & wear reduction, dissipation of heat and providing cooling However, a key factor for the failure of lubricants while in operation especially at elevated temperature is thermal degradation [1]. Vegetable oils due to their biodegradability are considered suitable alternative to petroleum-based lubricants for machining processes. Low oxidative and thermal stability challenges of vegetable oil as a biodegradable lubricant are enhanced with nanoparticles [2].

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Heat transfer enhancements by the dispersion of nanoparticles has attracted their use for the improvement of base fluid thermal and tribological properties [3]. Thermal degradation of base lubricants with dispersion of nanoparticles are retarded for about 10 min [4] due to improved thermal properties. The tribological properties of palm oil blended with 0.1% vol. of hexagonal boron nitride (hBN) was enhanced as reflected in the reduction of coefficient of friction and wear in comparison with the pure palm oil and commercially available engine oil SAE 15W40 [5]. Viscosity of lubricants are enhanced and by extension the viscosity index which is a critical factor in defining oil characteristics improved with addition of nano-additives [6]. However, reports on thermal stability of biolubricants enhanced with nanoparticles are scarce in literature [7] and there is need for the understanding thermal stability of biolubricants enhanced with nanoparticles for sustainable application. The current study therefore intends to evaluate thermal stability of all lubricants and ascertain the level of improvement for thermal stability with dispersion of nanoparticles.

2 Methodology

The base oil was dispersed with graphene and maghemite nanoparticles at 0.1% volume concentration to produce nanolubricants. The nano dispersion was stirred using higher shear homogenizer (IKA T25 digital Ultra-Turrax, Germany) for 60 min at 3200 rpm and further subjected to sonication process using ultrasonication bath (RK 514 BH, Bandelin Sonorex, Berlin-Germany) for 4 h to ensure a stable suspension and lubricants of uniform dispersion. Thermal stability, viscosity and anti-wear properties of the base oil and nanolubricants were evaluated using thermogravimetric analyzer, Brookfield (DV-II+PRO) viscometer and four ball (friction test) tester respectively.

3 Results and Discussion

3.1 Thermogravimetric Analysis

Figure 1 represents the TGA curves indicating the commencement of the oxidation onset temperature for both the base lubricant and the lubricant enhanced with nano-particles additives as 350 °C, 359.09 °C and 381.82 °C respectively for CCO, MGCO and XGCO, respectively. The results of the TGA shows increase of mass loss for all the lubricants as temperature increases resulting in the removal of volatile substance. However, the speed of oxidation (slope of TGA curve) of the base oil without nano-particles was observed to be much faster than that of nanolubricants and this could be attributed to the improved oil retention capacity of the nano-enhanced lubricants (MGCO and XGCO) [4]. The findings reveals that the oxidation onset temperature of the nano-enhanced biolubricants can be delayed for 9.09 °C and 31.82 °C respectively for maghemite and graphene dispersed nanolubricants. This finding is in conformity with the observation of Ali et al. [1] when they show that the onset temperature of lubricant with nano-additives can be delayed due to improved oil retention capacity.

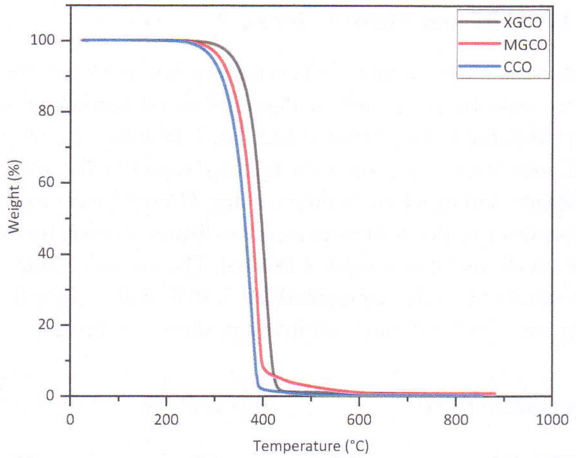

Fig. 1. Thermogravimetric Analysis (TGA) plot of the tested lubricants showing the thermal degradation of lubricants under thermal heating process.

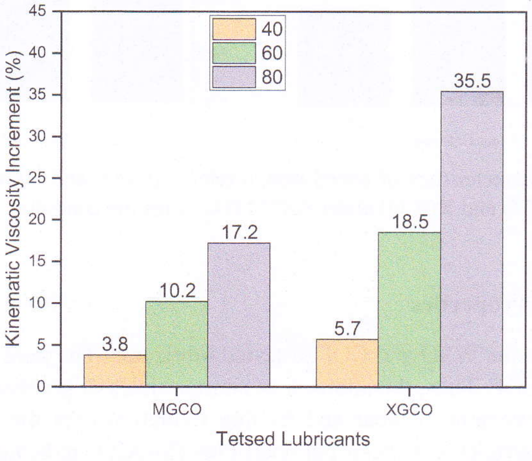

Fig. 2. Kinematic Viscosity Increment base lubricants with nano-additives under temperature variation

Table 1. Augmentation of Lubricant viscosity index with nanoparticle inclusion

Tested lubricants	Viscosity index	Viscosity index increment (%)
CCO (pure oil)	231	–
MGCO (maghemite)	248	7.36
XGCO (graphene)	263	13.85

3.2 Kinematic Viscosity and Viscosity Index

The kinematic viscosity of tested lubricants is represented in Fig. 2. An improvement of kinematic viscosity was observed with the nano-enhanced lubricants over the pure base oil for the varying temperature ranges evaluated. The kinematic viscosity of the CCO base lubricant at 60 °C was observed to improve by 10.2% and 18.5% respectively with the addition of maghemite and graphene nanoparticles. Higher viscosity index is desirable for lubricant performance as that will enhance tribo-film formation for efficient boundary lubrication under a wide range of temperatures [6]. The viscosity index of the enhanced biolubricant was observed to be augmented by 7.36% with maghemite (MGCO) and 13.85% with graphene (XGCO) nano-additives as shown in Table 1.

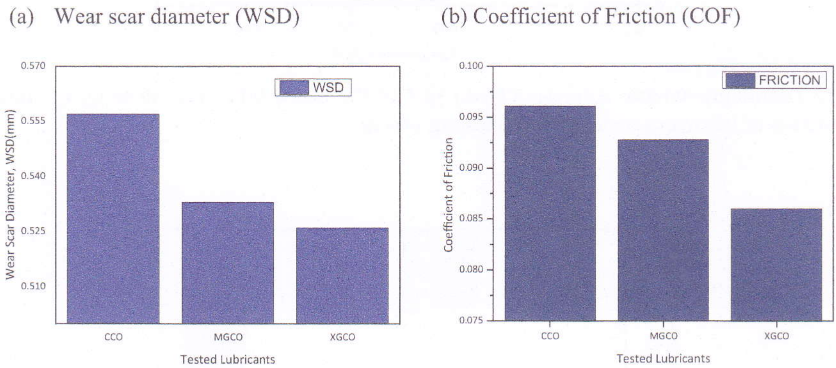

Fig. 3. Anti-wear characteristics of tested base lubricant (CCO) and lubricant enhanced with nano-additives (MGCO and XGCO) under ASTM D4172 testing condition.

3.3 Tribological Properties

Figure 3 represents the WSD and COF of tested lubricants. The pure coconut oil shows higher WSD and COF. Thus, the addition of nanoparticles of graphene and maghemite have shown improvement of wear and friction reduction over the pure biolubricant. Maghemite nanoparticles enhanced nanoparticles (MGCO) indicated 3.3% and 4.3% reduction of WSD and COF respectively in comparison with base biolubricants (CCO). A reduction of 10.4% and 5.6% in COF and WSD respectively was observed with graphene enhanced nanolubricant (XGCO) when compared with the base biolubricant (CCO). The addition of nanoparticles helps in the formation of tribo-film at the contacting surface thereby causing rolling effect between the asperities and thus reducing friction and wear [5, 6].

4 Conclusion

The properties of an enhanced vegetable oil with graphene and maghemite nanoparticles have been evaluated in terms of thermal stability, viscosity and tribological properties. The oil retention capacity of the nano-enhanced biolubricants were observed to improve over the base oil and that onset oxidation temperature of the nanolubricants can be delayed by 9.09 °C and 31.82 °C respectively for maghemite and graphene nanolubricants. The graphene and maghemite nanoparticles dispersion in the base biolubricant indicated a reduction of 10.4% and 3.3% respectively for COF as well as 5.6% and 4.3% respectively in terms of WSD in comparison with the base biolubricant (CCO). The results reveal that the graphene enhanced nanolubricant provided the best thermal stability and tribological properties. Thus, the addition of nanoparticles in biolubricant improves their performance thereby making them a competitor in the lubricant market regarding their dual potential of addressing environmental concern and energy saving.

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