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NANOSTRUCTURED AL_2O_3/GRAPHENE AS NANO-ADDITIVES IN COCONUT OIL AS A NANO/BIO-LUBRICANT TO ENHANCE ENGINE OIL PERFORMANCE

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ABSTRACT: The usage of internal combustion engines (ICEs) for both personal and industrial purposes is expected to persist beyond 2050. However, due to environmental concerns, there is a growing call to reduce global reliance on petrochemicals and lubricants derived from fossil fuels. To address this, new strategies are needed to enhance ICE performance by minimizing friction, wear, fuel consumption, and exhaust emissions. This approach would mitigate the depletion of mineral and fossil fuel reserves and minimise environmental pollution. This study focuses on enhancing ICE performance using nano-bio lubricants. These lubricants are formulated using 2D nanocomposites of Al_2O_3/graphene as new additives in coconut oil, with performance comparable to mineral-based engine oil 15W40. The Al_2O_3/graphene nanocomposite synthesized via thermal annealing was found to have a rich sp^2 domain with spherical/laminar morphology and an ultra-fine particle size (<10 nm). When formulated as a nanofluid, it indicated consistent colloidal stability. Valuable insights into the tribological mechanism were acquired through several characterization techniques, containing friction and wear analysis. Reductions in the coefficient of friction (by 28%), specific fuel consumption (by 8%), and the emissions of exhaust pollutants (CO, SO_2, and NOx) were the significant achievements of optimizing a 2D tribological system using coconut oil formulation. This study showcases the advantages of utilizing nano-bio lubricants, which are developed with coconut oil and 2D-based hybrids as base stock and additives. These solutions can be applied to other areas where lubricants are essential such as improving fuel consumption while reducing environmental pollution to address global challenges.

Keywords: bio-lubricants, friction, nano-additives**,** wear

1. INTRODUCTION

In a contemporary, dynamic industry and environmentally conscious society, it is an escalating necessity to mitigate the environmental pollution caused by internal combustion engines (ICEs). This research focuses on saving energy and reducing the usage of fossil fuel and mineral reserves via enhanced lubrication, which reduces friction and wear in ICEs.

In this circumstance, bio-lubricants and nano-additives can play a pivotal role. Examples of nanomaterials added to lubricants include metal oxides of Al_2O_3, TiO_2, $TiSiO_4$ and recently reported 2D graphene derivatives. For example, (Gulzar et al., 2017) used 0.75 wt.% of $TiSiO_4$ (~ 50.0 nm) as a nano-additive in palm-trimethylolpropane (PTMP) ester and observed a 68% reduction in the coefficient of friction (COF) and a 50% reduction in the wear volume. (Philip et al. 2019) observed the enhancement of tribological performance by adding 0.50 wt.% of nano CuO (~ 50.0 nm) to coconut oil (CCO). (Abere J, 2017) utilized nanoparticles of Al_2O_3 (20.0 nm), SiO_2 (5.0 – 15.0 nm) and graphite (35.0 – 80.0 nm), 0.10 wt.% with untreated rapeseed oil and multigrade formulated mineral oil 15W40 and observed the enhanced tribological performance with combined additives; nanoparticles with zinc-dialkyldithiophosphate (ZDDP). (Philip et al., 2019) Acknowledge the optimized COF and wear reduction performance by the combination of CCO and hybrid Ce-Zr nanoparticles, 0.62 wt.%, with improved thermo-physical properties. (Ali et al., 2016) emphasized the enhanced tribological performance of Al_2O_3 nanoparticles (8.0 – 12.0 nm), 0.25 wt.% as an additive in formulated mineral oil 5W30 and revealed reductions of COF (35%) and wear rate (21%). (Meng, Su, & Chen, 2017) who studied the tribological properties of graphene, used mineral oil 10W40 as base-stock to blend with supercritical (Sc)-Ag/graphene nanocomposite (Sc-Ag/GN: spherical, 4.0–10.0 nm) as nano-additives and observed the reduction of COF (30.4%) and WSD (27.4%) with 0.06% ~ 0.10 wt.% concentration.

Bio-lubricants have been demonstrated to exhibit superior biodegradability, low toxicity, and higher viscosity index, compared to mineral-based lubricants. They are also more recyclable and renewable and are thus good candidates to substitute for mineral-based lubricants (Syahir et al., 2017). Nonetheless, one set of limitations observed for bio-lubricants are their low-temperature characteristics; wax formation, poor cold flow, high pour point (PP), and low oxidative stability, all of which are qualities in need of enhancement (Syahir et al., 2017). There are numerous bio-lubricants containing plant oils or animal fats in use with reasonably similar molecular structures, commonly known as triglyceride molecules (Syahir et al., 2017). CCO has been selected in this research as the bio-base stock, because of the excellent availability.

The ICE is a heat engine, which converts chemical energy into kinetic energy via a combustion process with an approximate thermal efficiency of around 20 – 30% for gasoline and diesel engines (Tung & McMillan, 2004). Energy losses through heat transfer, sound generation and friction contribute to the low thermal efficiency (Tung & McMillan, 2004). (Ali et al., 2016) Estimated that 17-19% of the power generated by an engine will be lost through friction, of which perhaps the relative motion of the piston ring assembly and cylinder liner interface will account for 40-50% of frictional power losses within an ICE: this was later confirmed by (Jia et al., 2018).

This paper investigates the tribological behaviour of nano/bio-lubricants on ICE components. Particular emphasis is placed on the piston ring cylinder liner interface, where the use of nanoparticles as engine oil additives with bio-based sample formulations will be compared with the performance of a conventional multigrade mineral-based lubricant (15W40). The ambition is to identify the optimal engine oil formulation which reduces friction and wear, thus improving fuel economy and reducing exhaust emissions. It therefore follows that optimizing the ICE performance saves energy and reduces the depletion of fossil fuels and mineral reserves for a stable and sustainable environment.

2. METHODOLOGY

Mineral-based multigrade engine oil 15W40 as the reference oil and coconut oil (CCO) as the bio-based lubricant were selected respectively. Al_2O_3/graphene (G) nanocomposite was synthesized via thermal annealing (Jastrzębska et al., 2017) using nanoparticles Al_2O_3 and G as nano-additives to formulate sample blends. Synthesized nanocomposites were characterized using Transmission Electron Microscopy (TEM), X-ray powder diffraction (XRD), Raman, and X-ray Photoelectron Spectroscopy (XPS).

In this investigation, five sample formulations, including 15W40 as reference oil, were utilized. CCO was utilized as the base stock after enhancing its physicochemical properties (Hettiarachchi et al., 2023). Three weight concentrations of Al_2O_3/G were used with Oleic acid as the surfactant. All the samples were blended using an ultrasonic mixture and further agitated using a magnetic stirrer hot plate. A UV-Vis spectrophotometer was used to analyze the dispersion stability of formulated sample blends.

Segments of a piston ring and a cylinder liner of an ICE were used with a Linear Reciprocating Tribometer (LRT) to investigate the tribological characteristics of sample blends. A twenty-five (25) test conditions; combinations of 5 loads (120, 140, 160, 180 & 120 N) with 5 velocities (15, 20, 30, 40 & 50 Hz) at an elevated temperature of 140 °C were applied to simulate real ICE performance following guidelines of ASTM G181-11.

Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX) and 3D noncontact optical profilometry techniques were utilized to analyze wear scars of test specimens following the LRT tests. A rheometer and a thermogravimetric analyzer were utilized to study the rheometric behaviour and thermal and oxidative stability of the formulated coconut oil (FCO). A dynamometer test rig with 4.8 kW capacity and an exhaust gas analyzer were used to investigate the specific fuel consumption and exhaust emissions of formulated sample blends and compared them with the reference oil 15W40.

3. RESULTS AND DISCUSSION

The results of the TEM analysis revealed the average particle size for nanoparticles Al_2O_3/G as 10.0 ±0.3 nm with lattice fringe spacing for G in Al_2O_3/G as 0.37±0.01 nm, (Hayes et al., 2015; Seehra et al., 2015) with spherical/ laminar morphology, which are very vital properties to infiltrate through ultrafine asperities of piston ring cylinder liner interface (Meng, Su, & Chen, 2016; Song, Yan, & Ji, 2019) in comparison to the reported ICE lubrication film thickness (Garcia-Atance Fatjo et al., 2016). The XRD, Raman and XPS analyses confirmed the synthesized nanocomposite as Al_2O_3/G (Baragau et al., 2020; Kellici et al., 2014; Meng et al., 2016; Pakharukova et al., 2017).

From the LRT test results it is observed that the FCO can reduce the coefficient of friction (COF) by 7% for all test conditions (mean) compared with the reference oil (15W40) with a maximum COF reduction of 53% under the 180 N load with 50 Hz sliding velocity (frequency) without any additives. The sample lubricant containing Al_2O_3/G 0.1 wt.% as nano additives in FCO (FCO+Al_2O_3/G 0.1 wt.%) dominated throughout all 25 test combinations resulting in the reduction of the overall coefficient of friction (COF) by 28% with a maximum of 59% COF reduction for the 200 N/50 Hz load/frequency combination. From the UV-Vis analysis, it is observed that the sample FCO+Al_2O_3/G 0.1 wt.% has different degrees of sedimentation during the 0–72 h period with consistent colloidal stability thereafter throughout the experiment period (Gulzar, 2017; Hou et al., 2021). The thermogravimetric analysis confirmed the improved thermal and oxidative stability of FCO than CCO under the airflow. The presence of the chemicals added to improve the physicochemical properties of CCO could have contributed to this effect (Hettiarachchi et al., 2023). From the rheometric analysis, the FCO demonstrated improved shear stability compared to the reference oil under increasing temperatures (60, 80, 100, & 120 °C).
From the dynamometer test results it is examined that the reduction of specific fuel consumption by 8% by the sample FCO+Al_2O_3/G 0.1 wt.%. In addition, the reduction of CO, SO_2 and NO_x emissions was revealed from exhaust gas analysis. The ultra-fine alumina particle size (10.0 ± 0.3 nm), spherical/laminar morphology and low crystallinity when hybridized with 2D graphene have been attributed to dispersion stability and tribological enhancement. The formation of a protective tribo-film on the sliding interface was revealed through EDX analysis, showing the deposition of C, Ni, Cr, O, Mo, and K with traces of Al on wear surfaces, which completely covers the underlying Fe material.

4. CONCLUSION

The outcomes of linear reciprocating tribometer (LRT) tests, scanning electron microscopy (SEM) micrographs, energy dispersive X-ray spectroscopy (EDX) surface analysis, 3D optical analysis, exhaust emissions and specific fuel consumption analyses have proven the significant benefits of the tribological properties of coconut oil and Al_2O_3/Graphene nano-lubricant (FCO+Al_2O_3/G 0.1 wt.%).
The formation of a protective layer on the wear surface supported by secondary mending and polishing effects is further elucidated by SEM micrographs confirming the above phenomenon. During elastohydrodynamic lubrication (EHL), reduction of COF above 50% specifically at higher reciprocating velocities could be assigned to the laminar/spherical morphology of Al_2O_3/G nano-additives, which could be attributed to rolling or ball-bearing effect in place of sliding lubrication. Improved heat transfer attributes of coconut oil with Al_2O_3/Graphene nano/bio-lubricant were confirmed with the reduction of NO_x emissions emphasizing the comparatively low combustion temperature compared to reference oil (15W40).

5. ACKNOWLEDGEMENT

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